Fishery Data Series No. 00-14

Stock Assessment of Dolly Varden in the Chilkoot Lake Drainage, 1997-1998

by

Randolph P. Ericksen

August 2000

Alaska Department of Fish and Game **Division of Sport Fish**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

FISHERY DATA SERIES NO. 00-14

STOCK ASSESSMENT OF DOLLY VARDEN IN THE CHILKOOT LAKE DRAINAGE, 1997-1998

by

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ABSTRACT

Abundance and sport exploitation of Dolly Varden *Salvelinus malma* overwintering in Chilkoot Lake near Haines in Southeast Alaska were studied to add to the understanding of this important stock. A mark-recapture experiment was used to estimate abundance of Dolly Varden ≥220 mm FL in Chilkoot Lake during the winter of 1997-1998. Growth and sustained yield were also modeled for this population. Dolly Varden were also sampled from the Chilkoot sport harvest to estimate the exploitation rate and age, sex, and size composition of the harvest.

Technicians marked a total of 2,678 Dolly Varden ≥220 mm FL in Chilkoot Lake during fall 1997. During spring 1998, technicians examined a total of 1,699 Dolly Varden ≥220 mm FL in Chilkoot Lake and the lake outlet, 35 of which were marked. Using a Peterson estimator stratified by size, I estimated that 109,152 (SE = 21,065) Dolly Varden ≥220 mm FL overwintered in Chilkoot Lake. Mean size of Dolly Varden harvested in the Chilkoot sport fishery during 1998 was 361 mm (SE = 4) FL and 460 g (SE = 16). Dolly Varden in the angler harvest were most commonly (55%) males and age 5 (40%). Chilkoot Dolly Varden growth was best described using a Gompertz growth curve. I estimated the exploitation rate of Dolly Varden ≥220 mm FL in this fishery at 0.008 (90% CI = 0.003 to 0.014). Per recruit analysis was used to determine that this exploitation rate was sustainable and could be increased. However, the exploitation rate in 1998 was probably much lower than average due to emergency fishery restrictions, and the exploitation rate during the 1980s may have been unsustainable.

Key words: Dolly Varden, *Salvelinus malma*, overwinter abundance, mark-recapture, harvest, exploitation rate, age composition, sex composition, size composition, growth, weight-length, sustained yield, per recruit, Chilkoot Lake, Chilkoot River, Haines, Southeast Alaska.

INTRODUCTION

The purpose of this study was to gather baseline data on the Dolly Varden *Salvelinus malma* population overwintering in Chilkoot Lake. The Chilkoot Lake and River sport fishery is one of the largest freshwater sport fisheries in Southeast Alaska, and it maintains the largest harvest of Dolly Varden in the region. The sport fishery was monitored through a creel survey from 1984 through 1990 (Neimark 1985, Mecum and Suchanek 1986, 1987, Bingham et al. 1988, Suchanek and Bingham 1989, Ericksen and Bingham 1990, Ericksen and Marshall 1991a) and through the Statewide Harvest Survey (SWHS, Mills 1979-1994, Howe et al. 1995-1999) from 1977 through the present. The harvest of Dolly Varden in the Chilkoot fishery peaked in 1985 at over 14,000 Dolly Varden and has steadily declined since that time, suggesting the population might have been overexploited. As a result of this decline, the bag limit for Dolly Varden in the drainage was reduced from 10 to 2 per day in 1994. Because of the importance of the Chilkoot Dolly Varden sport fishery, current estimates of population size and exploitation rate were desired to enable better-informed decisions regarding the efficacy of regulations to protect the population.

Dolly Varden have a complex life history. Anadromous Dolly Varden commonly reside in lakes and large rivers during winter, migrate to sea in spring or early summer, and return to their natal streams or lakes in fall, to spawn. In Southeast Alaska, Dolly Varden migrate to sea for the first time at age 2-4, may migrate between several freshwater systems during a given year, and may overwinter in non-natal systems (Armstrong 1965). Dolly Varden may also overwinter in salt water, but having once selected a lacustrine overwintering site, they are thought to continue using that site as winter habitat (Bernard et al. 1995). Dolly Varden tagged in Southeast Alaska have been recaptured up to 202 km from their overwintering site (Ericksen and Marshall 1991b).

Chilkoot Lake is located about 16 km northeast of Haines and easily accessed by road. It is a glacially turbid lake approximately 702 hectares in area, with a mean depth of 54.5 m (Figure 1). The lake outlet (Chilkoot River) flows about 1.6 km to Lutak Inlet and is closely paralleled by a

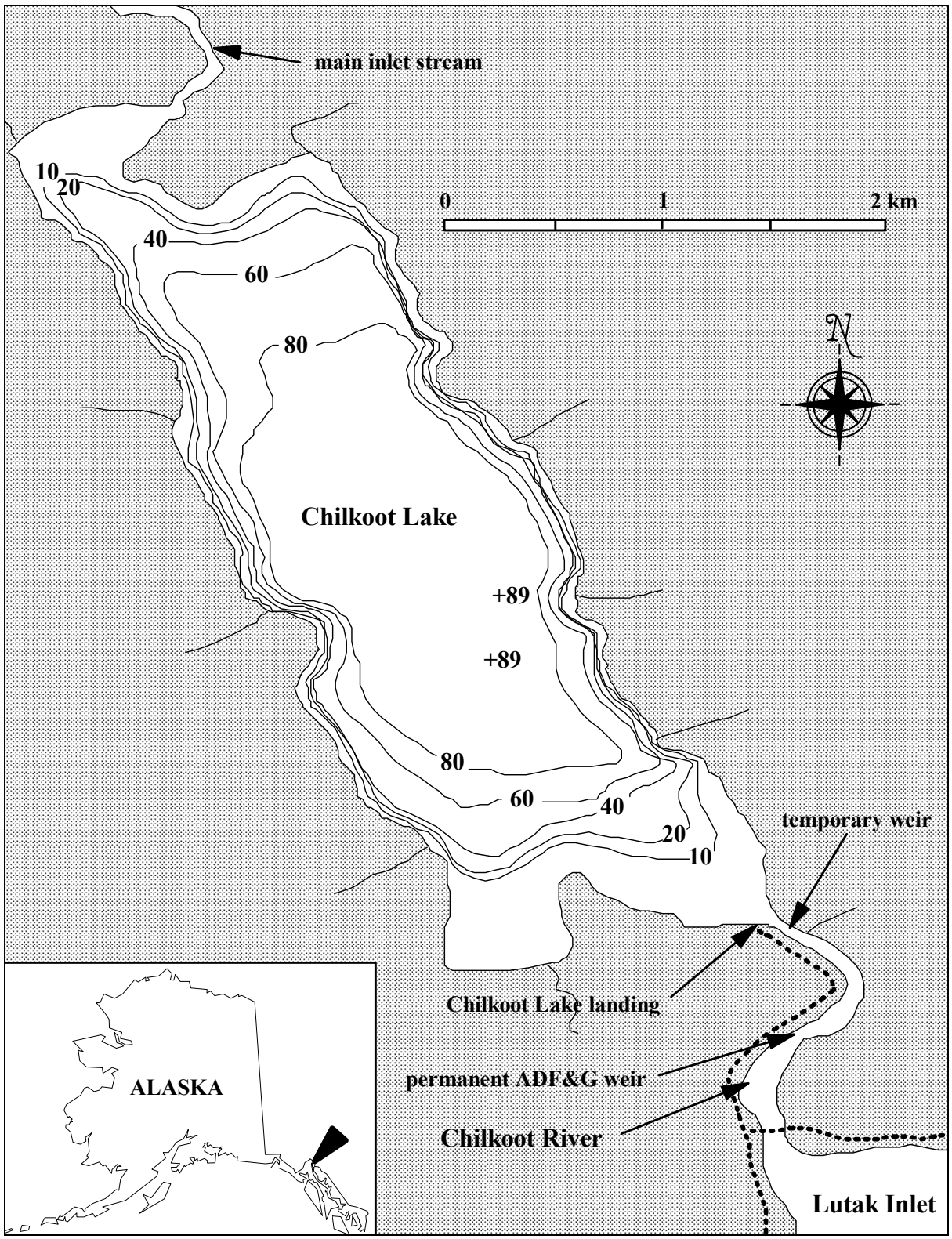


Figure 1.– Chilkoot Lake and River study area, showing sampling locations and lake depth contours (m).

road (Figure 1). Resident and anadromous fish in the drainage include Dolly Varden, cutthroat trout *Oncorhynchus clarki*, eulachon *Thaleichthys pacificus*, threespine stickleback *Gasterosteus aculeatus*, sculpin *Cottus sp*., and sockeye *O. nerka*, coho *O. kisutch*, pink *O. gorbuscha*, and chum salmon *O. keta*.

Dolly Varden harvests in the Chilkoot drainage were sampled for size and age in 1989 and 1990 (Ericksen et al. 1990, Ericksen and Marshall 1991b). Fish sampled were age 4-11 years; the most common age in 1989 was 6 years, and 7 years in 1990.

Dolly Varden harvested in the Chilkoot sport fishery could include a significant number of fish that had overwintered elsewhere. An estimated 27 of 1,111 Dolly Varden harvested in the Chilkoot sport fishery in 1990 had spent the previous winter in Chilkat Lake (Ericksen and Marshall 1991b). Other nearby freshwater systems such as the Ferebee, Katzehin, Skagway, and Taiya rivers might also provide winter residence for fish harvested in the Chilkoot River.

The objectives of this study were:

1. to estimate the abundance of Dolly Varden ≥220 mm FL overwintering in Chilkoot Lake during the winter of 1997–1998;
2. to estimate the age, sex, and size composition of Dolly Varden in the Chilkoot sport harvest from June 28 to October 17, 1998; and
3. to estimate the exploitation rate of Dolly Varden ≥220 mm FL overwintering in Chilkoot Lake by the Chilkoot sport fishery from June 28 to October 17, 1998.

I also sampled the emigration for size composition and modeled growth and sustained yield of Chilkoot Dolly Varden, using the age-based data collected in this study. These results expand knowledge of Dolly Varden biology for use in management of the Chilkoot population.

METHODS

OVERWINTER ABUNDANCE

The abundance of Dolly Varden ≥220 mm FL overwintering in Chilkoot Lake during the winter of 1997–1998 was estimated with a 2-event mark-recapture experiment. Dolly Varden were captured along the perimeter of Chilkoot Lake (Figure 1) between September 16 and October 31, 1997 in large minnow traps, hoop traps and beach seines. A few fish (97) were also captured in the main inlet stream to Chilkoot Lake between October 3 and 12. Fish captured were assumed to overwinter in the lake. Every Dolly Varden ≥220 mm FL captured was measured to the nearest 1 mm, marked with an adipose finclip, and released. Some (207) of them were also marked with either visual implant (VI) or t-bar anchor tags. Dolly Varden <220 mm FL were counted and released.

During spring emigration between April 9 and May 26, 1998, Dolly Varden were captured and examined for marks at the lake outlet (Chilkoot River). Fish were also captured in Chilkoot Lake between April 14 and June 1, 1998. All captured Dolly Varden ≥220 mm were counted, measured for length, examined for missing adipose fins, and released. Dolly Varden ≥220 mm captured in the lake were marked with a shallow clip of the lower caudal fin (to prevent double sampling). Dolly Varden <220 mm FL were counted and released.

Spring sampling in Chilkoot River was accomplished by two methods. A temporary vexar panel weir with two fyke net traps was operated immediately downstream of the lake (Figure 1) between April 9 and May 8, 1998. This gear was not fished on April 14, when the ice went off the lake and down the Chilkoot River, or on April 25–28, to avoid both impeding the migration of eulachon and conflicts with the eulachon subsistence fishery. In addition, high water prevented the weir from being fish-tight on April 20–24 and on May 7–8. The temporary weir was pulled on May 9, and the permanent ADF&G picket weir located approximately 0.75 km downstream of the lake (Figure 1) was installed. The weir was fish-tight on May 15, when the picket spacing was reduced from 63.5 mm (2.5 in.) to 31.8 mm (1.25 in.) on center. The picket weir was pulled on May 26, when the river level became too high to continue sampling.

All Dolly Varden ≥220 mm captured in the river were also examined for a lower caudal finclip (indicating that it had already been sampled in the lake), marked with a shallow clip of the

upper caudal fin (to prevent double sampling), and released. Every char ≥350 mm FL captured in the river was also marked with an individually numbered t-bar anchor tag. These tags were used to help describe migration patterns of these sea-run char as they were recovered around northern Southeast Alaska.

The validity of a Petersen mark-recapture experiment rests on several assumptions: (a) that every fish has an equal probability of being marked during event 1, or that every fish has an equal probability of being captured in event 2, or that marked fish mix completely with unmarked fish; (b) that recruitment and "death" (emigration) do not both occur between sampling events; (c) that marking does not affect catchability (or mortality) of the fish; (d) fish do not lose marks between sample events; (e) all recovered marks are reported; and (f) that double sampling does not occur (Seber 1982).

Length data from both fall and spring sampling events were compared with two Kolmogorov-Smirnov (KS) 2-sample tests ($\alpha = 0.10$) to provide evidence for the validity of assumption (a). The abundance estimator was stratified by size groups after a contingency table analysis was used to determine appropriate groups because size selective sampling was detected during the second sampling event (the second χ^2 test). The remaining assumptions are considered in the Discussion section.

The overwintering abundance of Dolly Varden ≥220 mm FL was estimated using Chapman's modified Petersen estimator for a closed population (Seber 1982):

$$\hat{N}_s = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1 \qquad (1)$$

$$var[\hat{N}_s] = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \qquad (2)$$

where s is the size group of interest, n_1 is the number of Dolly Varden of size group s marked in the lake during the fall of 1997, n_2 is the number of Dolly Varden of size group s examined at the lake outlet during the spring of 1998, and m_2 is the subset of n_2 that had been marked in the fall.

AGE, SEX, AND SIZE COMPOSITION OF THE HARVEST

Dolly Varden were sampled in the Chilkoot sport fishery between June 28 and October 17, 1998. Sampling was constant over time and directed toward maximizing the number of Dolly Varden sampled. Constant sampling effort throughout the season was assumed to yield proportional sampling rates over time. Sampling was not initiated earlier because less than 7% of the total Dolly Varden harvest in this fishery in 1989 occurred between May 8 and July 2 (Ericksen and Bingham 1990). The Lutak Inlet marine fishery was not sampled because less than 8% of the Dolly Varden occurred there in 1989. Because previous surveys suggested that 90% of the catch and harvest of Dolly Varden occurred above the weir (Ericksen and Marshall 1991a), the majority of the sampling effort was directed there. Similarly, most sampling effort was allocated to the late afternoon and evening to increase sample sizes. Sampling was conducted 5 days a week (Tuesday–Saturday).

The sampling procedure was consistent throughout the season. Each sample day, a technician sampled Dolly Varden in the angler harvest during two time periods: 1400 to 1700 hours and 1700 to 2000 hours. The technician first roved the fishery and inspected harvests above the weir, then below the weir, and, then sampled again above the weir. All Dolly Varden inspected were examined for missing adipose fins and sex, measured for length (to the nearest mm FL) and weight (to the nearest 10 g), and sampled for otoliths (to estimate age). The technician also collected CPUE data from anglers as time allowed.

Both sagittal otoliths were collected from harvested Dolly Varden whenever possible. Later in the season, the left otolith (right was used if the left was not available) was mounted on a glass slide (using thermoplastic cement) and ground down until the primordia were visible. Then the otolith was turned over and ground until the annuli were visible. A technician viewed the sectioned otolith on a Leica MS5 stereo-microscope with a 10× ocular, 1× objective, and 0.63-4.0× magnification changer, using oblique transmitted light, and counted the

number of hyaline zones (annuli) to estimate the age of the fish (see Appendix A for examples of otoliths and their age determinations). Length and weight compositions of the Dolly Varden harvest were estimated by standard methods for normally distributed data.

Proportions by age or sex were estimated by

$$\hat{p}_i = \frac{n_i}{n} \tag{3}$$

$$var[\hat{p}_i] = \frac{\hat{p}_i\ (1-\hat{p}_i)}{n-1} \tag{4}$$

where p_i is the proportion in the population in age/sex/size group *i,* n_i is the number in the sample belonging to group *i*, and *n* is the number in the sample that were successfully aged or sexed.

DOLLY VARDEN GROWTH

I modeled growth of Chilkoot Dolly Varden, using age and length data collected during this study and methods developed by Schnute (1981). Schnute's general (full) model contains four parameters: κ, γ, y_1, and y_2. The parameter κ is related to relative growth (equivalent to the Brody growth parameter, Ricker 1975), whereas the parameter γ influences the shape of the curve. The parameters y_1, and y_2 correspond to the mean length at the youngest (τ_1) and oldest (τ_2) ages, respectively. Schnute (1981) developed four cases for his model depending on whether κ and/or γ are equal to 0. A fifth case (equivalent to the LVB [Bertalanffy] growth model) was added to this by setting γ equal to 1 (Quinn and Deriso 1999, p. 155).

I fit the five cases to pooled length (dependent variable) and age (independent variable) data, using nonlinear least squares and assuming an additive error structure (a multiplicative model was not used because length variance did not appear to increase with age). The best case was selected, as long as parameter estimates were not significantly different from zero, by using the F-test procedure described in Schnute (1981).

I also used an allometric growth model (Quinn and Deriso 1999, pp. 129-131) to estimate the weight to length relationship of Chilkoot Dolly Varden. A multiplicative error structure was used because the variation in weight obviously increased with length.

HARVEST AND EXPLOITATION

Dolly Varden harvest estimates for Chilkoot Lake and Chilkoot River during 1998 were obtained from the SWHS (Howe et al. 1999). Because significant numbers of Dolly Varden which overwinter in other systems could be harvested in the Chilkoot sport fishery, I compared the marked fraction $\hat{\theta}$ of extra large (≥310 mm FL) Dolly Varden outmigrating to the fraction $\hat{p}$ of the sport harvest carrying marks. If $\hat{p} < \hat{\theta}$ then Dolly Varden immigration from other systems was indicated. Only extra large Dolly Varden were used in the comparison because anglers selectively harvested mostly this size class of Dolly Varden. If a chi-square test indicated that $\hat{p} < \hat{\theta}$, then methodology described in Bernard and Clark (1996) that is commonly used to estimate harvests using coded wire tags would be used to estimate the contribution of stocks that overwintered in Chilkoot Lake. The contribution estimate $\hat{r} = \hat{H}\,\hat{p}\,\hat{\theta}^{-1}$ and its associated variance would be calculated using the large-sample approximation as explained in Bernard and Clark (1996: Table 2), where $\hat{H}$ equals harvest in the Chilkoot sport fishery.

Length composition data from harvested fish were used to partition the harvest into size groups for comparison with abundance:

$$\hat{H}_s = \hat{H}\,\hat{p}_s \tag{5}$$

$$\begin{aligned} &\text{var}[\hat{H}_s] = \\ &\quad \text{var}[\hat{p}_s]\hat{H}^2 + \text{var}[\hat{H}]\hat{p}_s^2 - \text{var}[\hat{p}_s]\,\text{var}[\hat{H}] \end{aligned} \tag{6}$$

where $\hat{H}$ is the estimated harvest of Dolly Varden in the Chilkoot sport fishery and $\hat{p}_s$ is the estimated proportion of size *s* fish in the harvest.

The exploitation rate μ of size *s* fish that overwintered in Chilkoot Lake in this fishery was estimated:

$$\hat{\mu}_s = \frac{\hat{H}_s}{\hat{N}_s} \quad (7)$$

$$\mathrm{var}[\hat{\mu}_s] = \hat{\mu}_s\left(\frac{\mathrm{var}[\hat{H}_s]}{\hat{H}_s^2} + \frac{\mathrm{var}[\hat{N}_s]}{\hat{N}_s^2}\right) \quad (8)$$

where variance was approximated using the delta method (Seber 1982; note that $\hat{H}$ and $\hat{N}$ were independent in this experiment, because H was estimated by the SWHS).

ANALYSIS OF SUSTAINED YIELD

I modeled sustained yield using methods modified from Quinn and Szarzi (1993, approach 3) because early life survival and spawner-recruit relationships were not available for this population. This approach evaluates sustained yield relative to biological reference points (BRPs) for an arbitrary number of recruits (i.e., per recruit).

The per recruit analysis was based on the general recursion equation for abundance:

$$N_{a+1,t+1} = S_a N_{a,t} \quad (9)$$

where $N_{a,t}$ was the abundance at age *a* and year *t*, and S_a was the survival at age *a*. The calculations began by setting an age for full recruitment (a=r) to the fishable population and setting abundance at that time ($N_{r,t}$) to 1,000. I set r equal to age 3 in this analysis because that was the youngest age sampled in the harvest. Natural (instantaneous) mortality M was assumed constant and occurred simultaneously with instantaneous fishing mortality F_a. Total (instantaneous) mortality was calculated as

$$Z_{a,t} = M + F_a \quad (10)$$

with fishing mortality at age *a*:

$$F_a = s_a F \quad (11)$$

where F was the full instantaneous recruitment fishing mortality and angler selectivity (for fish as a function of length) was

$$s_a = 1 - \int_{l=290}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{290-\bar{l}_a}{\sigma}\right]^2} dl \quad (12)$$

where $\bar{l}_a$ was the mean fork length of age *a* fish determined from the growth model, σ was set to the average standard deviation of lengths about the mean for each age (45). The value 290 in equation (12) represents the fork length in mm below which anglers are assumed to voluntarily release their fish unless they were hooked badly. Angler selectivity reflects angler preference for retaining larger fish. Over 95% of fish sampled in the harvest during this study were ≥290 mm.

Harvest of age *a* fish in year *t* was

$$H_{a,t} = \mu_a N_{a,t} \quad (13)$$

where μ_a was the exploitation fraction:

$$\mu_a = \frac{F_a}{Z_a}(1 - e^{-Z_a}) \quad (14)$$

Survival was defined as a function of mortality:

$$S_a = e^{-Z_a} \quad (15)$$

and the survival from age *r* to age *a* was

$$\ell_a = \prod_{x=r}^{a-1} S_x \quad (16)$$

Age composition of the harvest under the model was compared to that observed in this study to provide a measure of model performance.

The spawning abundance per recruit was calculated as

$$Ns/Nr = \sum_{a=r}^{A} m_a \ell_a \quad (17)$$

where m_a was the proportion of mature fish at age a as a function of length:

$$m_a = 1 - \int_{l=300}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{300-\bar{l}_a}{\sigma}\right]^2} dl \quad (18)$$

The value 300 in equation (18) represents the length in mm at which Dolly Varden were assumed to be fully mature. This information came from a study of Anchor River Dolly Varden showing that the majority of fish <300 mm were immature and the majority >300 mm were mature (Larson 1990).

The spawning biomass per recruit was calculated as

$$Bs/Nr = \sum_{a=r}^{A} m_a \lfloor_a \overline{w}_a \qquad (19)$$

where $\overline{w}_a$ was the mean weight of age a fish calculated using the length-weight model developed in this study. The inclusion of weight in the model reflects the increasing value (weight and fecundity) of mature fish as they age.

The total harvest per recruit became

$$H = \sum_{a=r}^{A} \mu_a \lfloor_a \qquad (20)$$

and the exploitation rate (across ages) was calculated as

$$\mu = \frac{\sum_r^A H_{a,t}}{\sum_r^A N_{a,t}} \qquad (21)$$

My management objective was to maintain the spawning stock at a level necessary to sustain the population over the long term. Clark (1991) determined that a fishing mortality rate that reduced the spawning biomass to 35% ($F_{35\%}$) of the unfished level provided a yield near the maximum sustainable yield (MSY) for a variety of life history parameters for Alaska groundfish populations ($0.1 \le M \le 0.4$). Der Hovanisian (1994) evaluated sustained yield of rainbow trout in Blue Lake (near Sitka) and found that the fishing mortality rate that reduced the spawning abundance to 50% ($F_{50\%}$) of the unfished abundance was only slightly above that required to maximize the harvest of fully mature fish.

Thus, I selected four BRPs for this analysis. First, values of instantaneous fishing mortality ($F_{35\%}$) and the exploitation rate ($\mu_{35\%}$) that reduced the spawning biomass to 35% of the unfished level (i.e., F = 0) were calculated. Similar values ($F_{50\%}$ and $\mu_{50\%}$) were also calculated that reduced spawning abundance to 50% of the unfished level. This analysis was repeated for four values of natural mortality to assess the sensitivity of the results to changes in that variable.

RESULTS

OVERWINTER ABUNDANCE

Project staff captured 9,128 Dolly Varden in Chilkoot Lake (Figure 2) during fall 1997. Of those captured, 2,678 ≥220 mm FL were marked with an adipose finclip and released (Table 1). Eleven (11) mortalities were sampled for age, sex, length, and weight (Appendix B1). Capture rates of Dolly Varden peaked on September 24.

Project staff captured 2,626 Dolly Varden during spring 1998, of which 1,699 were ≥220 mm FL (Table 2); 84 of the Dolly Varden ≥220 mm FL were captured in Chilkoot Lake and marked with a lower caudal finclip (4 of these had been marked previously with an adipose finclip). The remaining 1,615 fish ≥220 mm FL (not including the 4 captured with lower caudal finclips) were captured in the Chilkoot River, and 31 of these had missing adipose fins. Thus, 1,699 unique fish ≥220 mm FL were examined and 35 marked fish recovered during spring, 1998. Appendix B2 contains data from 139 mortalities that were sampled for age, sex, length, and weight. Catches of Dolly Varden in the Chilkoot River peaked on May 1 (Figure 3). Larger Dolly Varden tended to emigrate earlier than smaller fish (Figure 4).

Length composition of sampled Dolly Varden ≥220 mm varied greatly between sampling events (Figures 5 and 6). The cumulative distribution function (CDF) of lengths of Dolly Varden (≥220 mm) marked in fall differed significantly from the CDF of marked Dolly Varden recaptured in spring (K-S test, $d_{max} = 0.265$, $P = 0.016$, Figure 6, top). Smaller marked fish were probably not as likely to emigrate as larger fish. Thus, the second sampling event was size-selective. Also, fish marked during fall were significantly smaller than those captured during spring (K-S test, $d_{max} = 0.416$, $P < 0.001$, Figure 6, bottom). This result suggests the first sampling event may have also been size-selective. These results indicate that the abundance estimate should be stratified by size. A series of chi-square tests (Table 3) were used to determine length strata for estimating the overwintering abundance. The resulting estimate was stratified by "medium" (220–279 mm FL), "large" (280–309 mm), and "x-large" (≥310 mm FL) char (Table 4). I

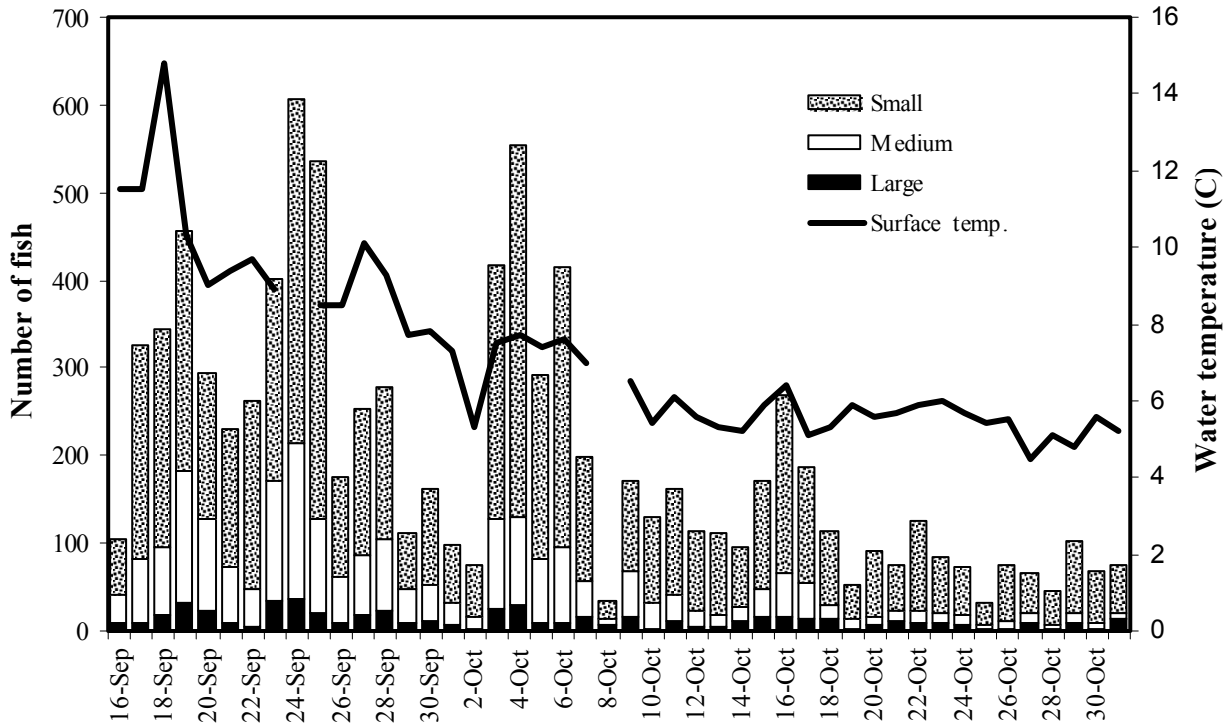


Figure 2.–Daily catch of small (<220 mm), medium (220–299 mm), and large (≥300 mm) Dolly Varden in Chilkoot Lake and the main inlet stream, and daily lake surface temperatures (°C), September 16 through October 31, 1997.

estimate that 109,152 (SE = 21,065) Dolly Varden ≥220 mm FL were present in Chilkoot Lake during winter 1997–1998, about half of them ≥310 mm (Table 4).

AGE, SEX, AND SIZE COMPOSITION OF THE HARVEST

Most (170) of the 184 Dolly Varden sampled from the sport harvest for otoliths, sex, length, and weight during 1998 were successfully aged (Table 5). Over 80% of the sampled Dolly Varden ranged from age 5 to 7. About 55% of harvested fish were males and 40% were age 5. The estimated mean size of Dolly Varden in the harvest was 361 mm FL (SE = 4 mm), and mean weight was 460 g (SE = 16 g).

DOLLY VARDEN GROWTH

I fit growth models to 320 pairs of length and age data collected during this study. The case 2 growth model with parameter estimates of y_1 = 85.4 mm (SE = 11.3), y_2 = 473 mm (SE = 17.0), and κ = 0.362 (SE = 0.055) yielded the most parsimonious fit to the data (Figure 7, Appendix B3). This model is equivalent to a Gompertz growth curve which contains both an inflection point (a period of accelerated growth at an intermediate age = 202 mm) and an asymptote (maximum size = 548 mm). The inflection point suggests that Chilkoot Dolly Varden achieve their maximum growth rate between age 3 and 4.

I fit the weight-length model to 249 pairs of weight and length data collected during this study (Figure 8). Parameter estimates for this model were α = -11.7 (SE = 0.2) and β = 3.02 (SE = 0.03).

HARVEST AND EXPLOITATION

Technicians conducted 1,628 interviews with anglers who had fished Chilkoot Lake and River during 1998 (Table 6). These anglers had fished a total of 2,999.7 hours and harvested 217 Dolly Varden from a catch of 946. Over

Table 1.–Number of Dolly Varden marked in the Chilkoot drainage during fall, 1997, by size class, sampling effort, time period, location, and gear type. Fish classified as medium "M" (220–299 mm FL), or large "L" (≥300 mm FL); sampling effort represented by total number of large minnow traps or hoop traps checked (#chk'd), or number of times the beach seine was set (#sets) during the time period.

	Chilkoot Lake															Main inlet stream				Total both sites		
	Large minnow traps				Hoop traps				Beach seine				Lake total			Hoop traps (only)						
Dates	#chk'd	M	L	Total	#chk'd	M	L	Total	#sets	M	L	Total	M	L	Total	#chk'd	M	L	Total	M	L	Total
09/16-09/20	120	440	89	529									440	89	529					440	89	529
09/21-09/25	120	527	106	633									527	106	633					527	106	633
09/26-09/30	120	284	70	354									284	70	354					284	70	354
10/01-10/05	120	299	43	342									299	43	342	11	15	28	43	314	71	385
10/06-10/10	99	187	21	208									187	21	208	20	26	23	49	213	44	257
10/11-10/15	120	106	45	151	5	2	0	2					108	45	153	15	3	2	5	111	47	158
10/16-10/20	119	96	29	125	9	34	23	57					130	52	182					130	52	182
10/21-10/25	120	54	35	89					4	0	4	4	54	39	93					54	39	93
10/26-10/31	132	50	37	87									50	37	87					50	37	87
Total	1,070	2,043	475	2,518	14	36	23	59	4	0	4	4	2,079	502	2,581	46	44	53	97	2,123	555	2,678

Table 2.–Number of Dolly Varden examined for marks and number of marked fish recovered during spring 1998 in the Chilkoot drainage, by size class, sampling effort, time period and location. M = 220–299 mm FL, L = ≥300 mm FL; sampling effort is the total number of days weir was operational (days), or number of large minnow traps (traps) checked during the time period; H/L indicates all fish were caught with hook and line gear.

	Chilkoot River						Chilkoot Lake						Total both sites					
		Examined			Marked			Examined			Marked		Examined			Marked		
Dates	Days	M	L	Total	M	L	Traps	M	L	Total	M	L	M	L	Total	M	L	Total
04/08-04/12	4	0	10	10	0	0	0						0	10	10	0	0	0
04/13-04/17	4	0	218	218	0	0	52	2	9	11	0	0	2	227	229	0	0	0
04/18-04/22	4	0	25	25	0	0	52	5	1	6	0	0	5	26	31	0	0	0
04/23-04/27	2	8	50	58	0	0	57	14	2	16	1	0	22	52	74	1	0	1
04/28-05/02	4	257	315	572	10	6	44	5	1	6	1	0	262	316	578	11	6	17
05/03-05/07	5	122	93	215	4	0	52	11	3	14	1	0	133	96	229	5	0	5
05/08-05/12	4	11	10	21	1	0	24	5	2	7	0	0	16	12	28	1	0	1
05/13-05/17	5	79	69	148	2	0	0						79	69	148	2	0	2
05/18-05/22	5	105	135	240	3	3	H/L	2	4	6	0	0	107	139	246	3	3	6
05/23-05/27	4	47	61	108	1	1	0						47	61	108	1	1	2
05/28-06/01	0						72	8	10	18	0	1	8	10	18	0	1	1
Total	41	629	986	1,615	21	10	353	52	32	84	3	1	681	1,018	1,699	24	11	35

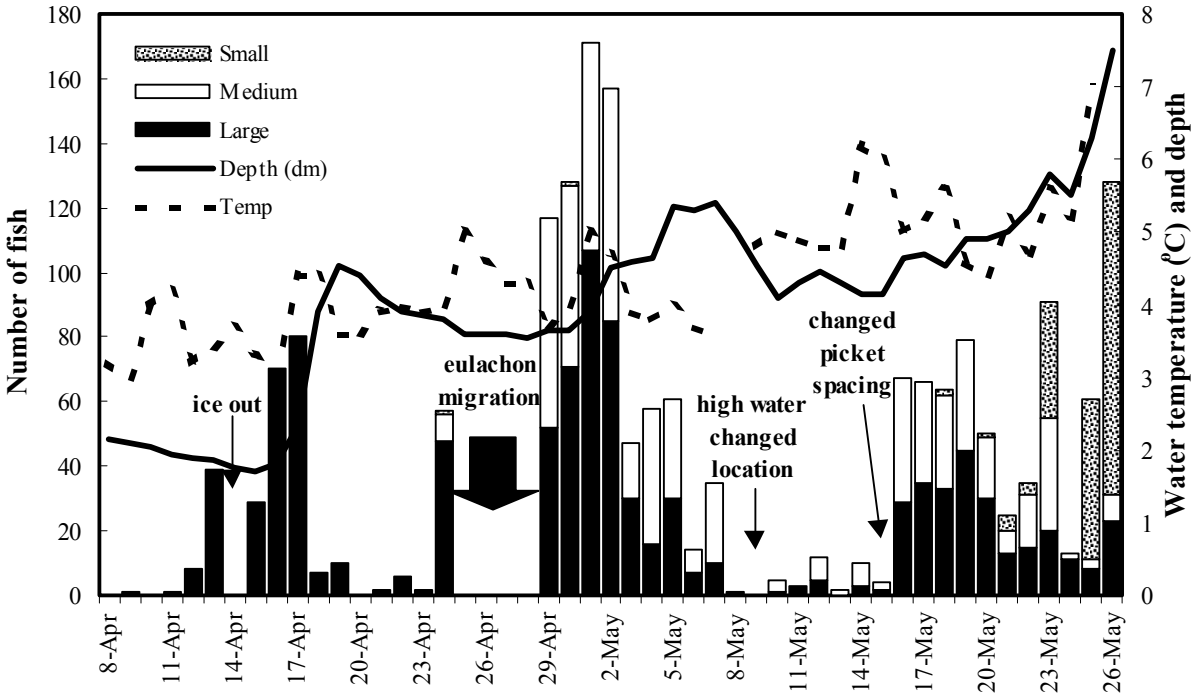


Figure 3.–Daily catch of small (<220 mm), medium (220–299 mm), and large (≥300 mm) Dolly Varden in the Chilkoot River (lake outlet), and daily water temperature (°C) and depth (decimeters), April 8 through May 26, 1998. Traps were not operated during the eulachon migration.

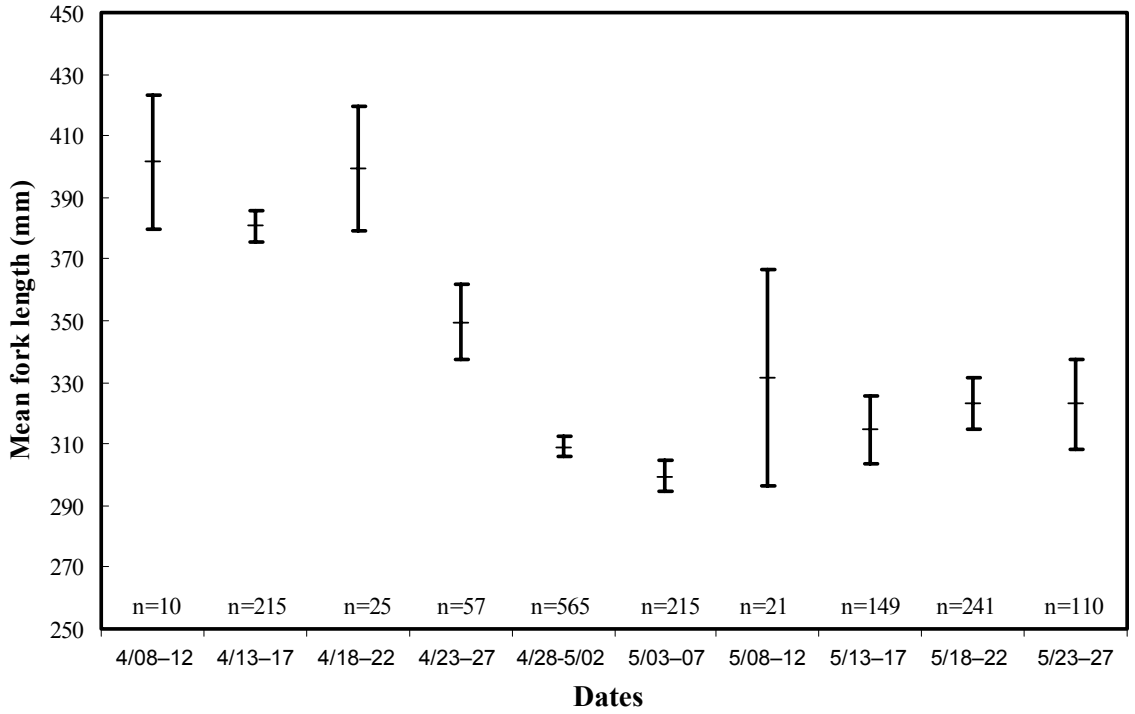


Figure 4.–Mean fork length of Dolly Varden captured in the Chilkoot River by 5-day period, 1998. Error bars represent 95% confidence intervals. Larger Dolly Varden tended to emigrate earlier.

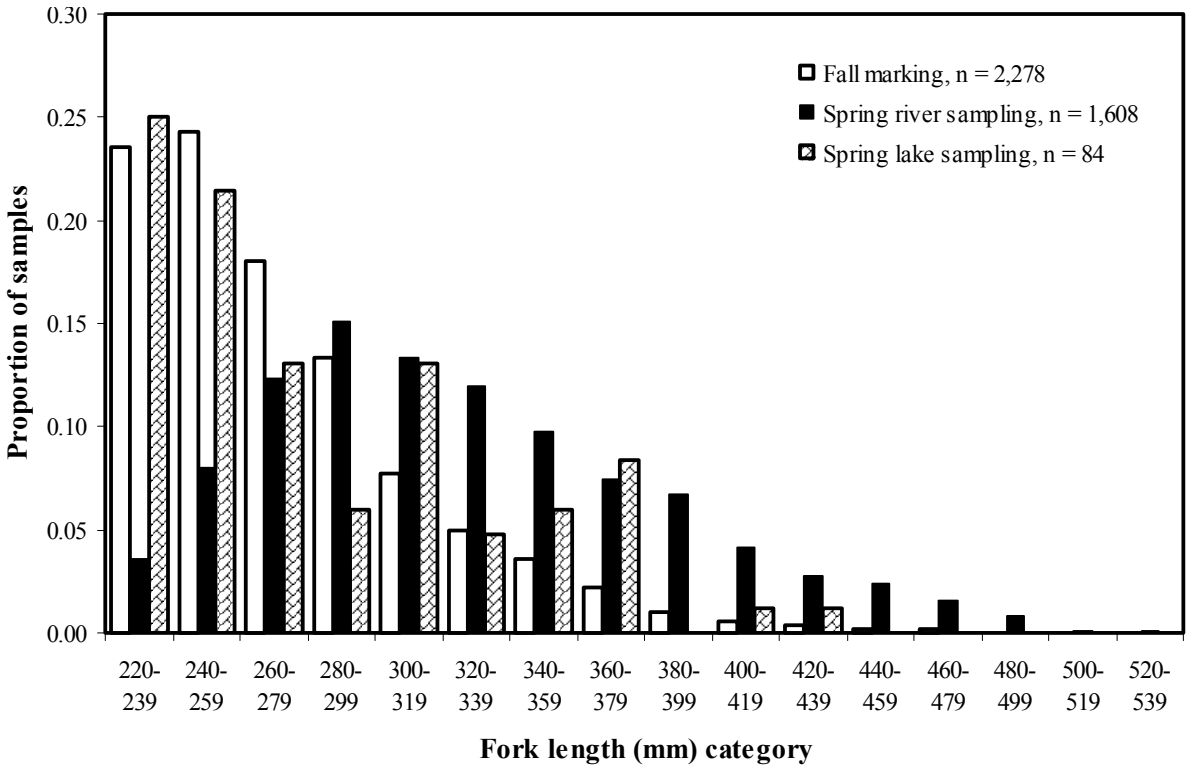


Figure 5.–Proportion of Dolly Varden ≥220 mm sampled by length category and sampling location in the Chilkoot drainage, 1997–1998.

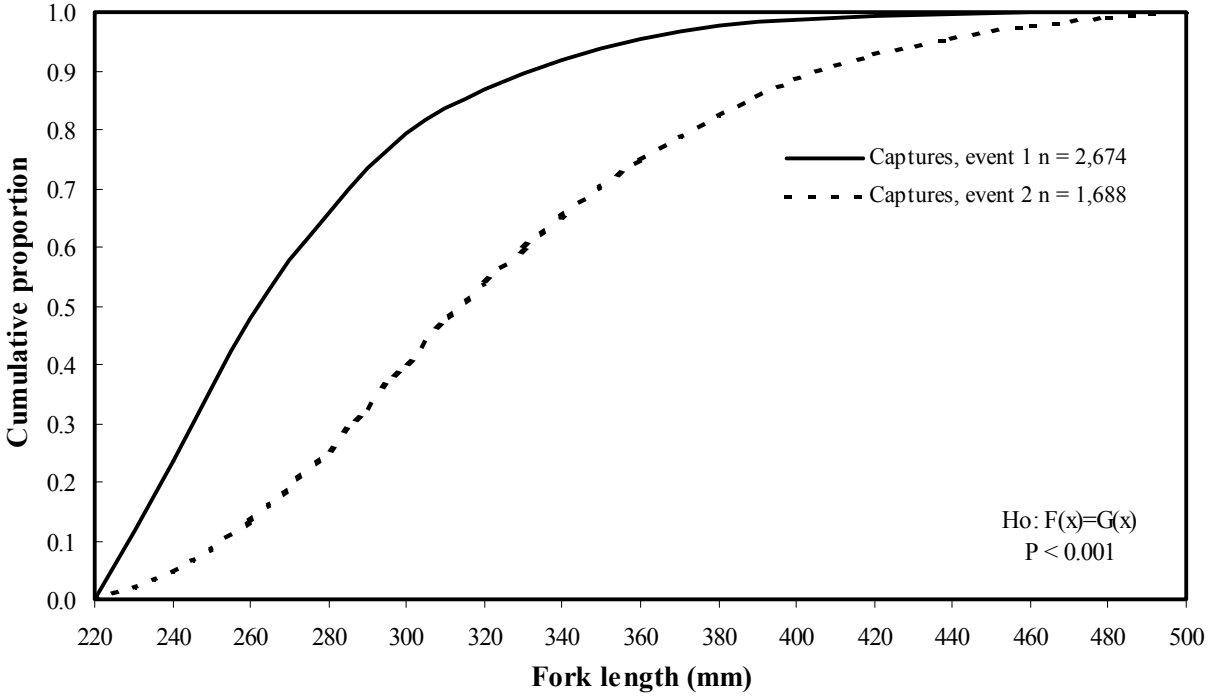
half of the Dolly Varden sampled (114) occurred at the Chilkoot Lake landing although only 20% of effort was sampled there (Appendix B4). Staff sampled 184 Dolly Varden in the harvest for marks and recovered 6 with missing adipose fins (Table 6). The marked ratio ($\hat{p}$) of 0.033 was greater than the $\hat{\theta}$ of 0.007 for extra large Dolly Varden sampled during outmigration (Table 4), therefore my data failed to suggest any immigration of other Dolly Varden stocks.

Howe et al. (1999) estimated that 902 (SE = 265) Dolly Varden were harvested in Chilkoot Lake and River sport fishery during 1998. This SWHS estimate was combined with size composition data to estimate that 29 (SE = 48) medium, 108 (SE = 92) large, and 760 (SE = 243) x-large Dolly Varden were harvested (Table 7). The exploitation rate of medium fish was estimated at 0.0008 (SE = 0.0003), large at 0.0059 (SE = 0.0025), and x-large at 0.0140 (SE = 0.0064), yielding a combined exploitation rate of 0.0082 (SE = 0.0026, Table 7).

ANALYSIS OF SUSTAINED YIELD

I compiled the modeled abundance, maturity, mean length and weight, and angler selectivity at age for analysis of sustained yield (Table 8). The modeled age composition of the harvest at a low exploitation rate (F = 0.1) was very similar to that observed in this study (Table 8).

BRPs for spawning abundance and biomass were nearly the same at lower values of M but diverged somewhat as M increased (Table 9). Variations in M had different effects on F and μ values. F values were relatively sensitive to changes in M compared to μ values (Table 9, Figure 9). Increasing values of M result in increasing values of $F_{X\%}$ and decreasing values of $\mu_{X\%}$. $F_{35\%}$ values for spawning biomass



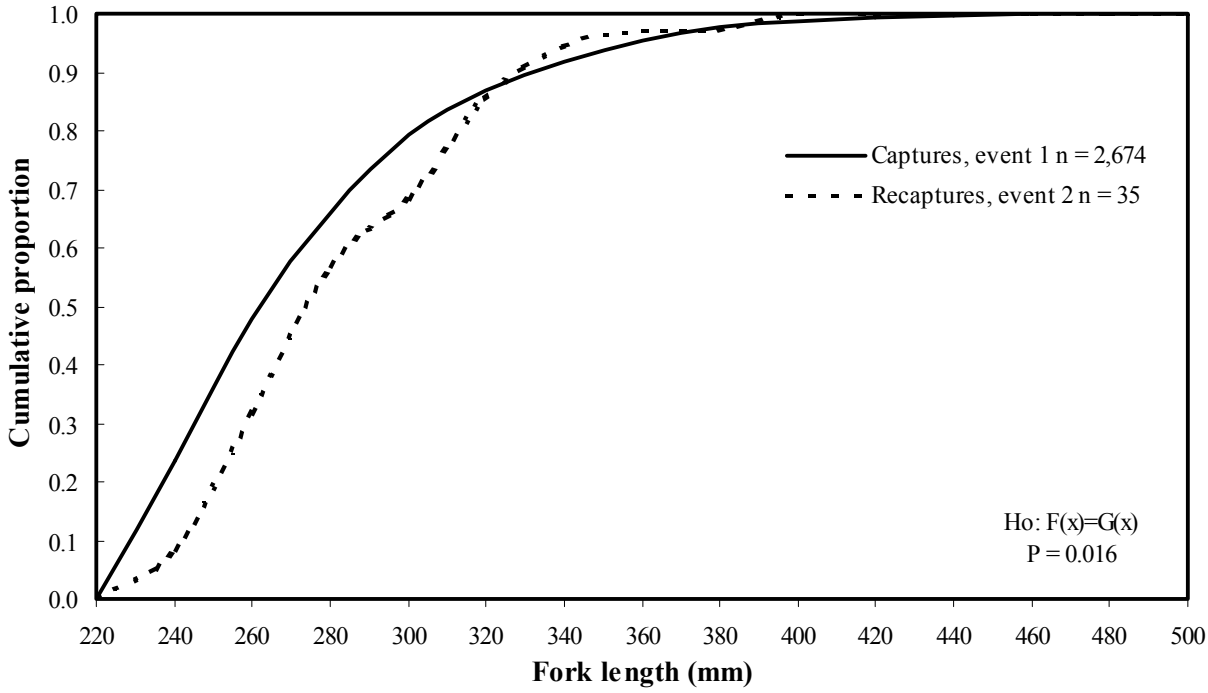


Figure 6.–Cumulative distribution function (CDF) of lengths (FL) of Dolly Varden ≥220 mm marked in the Chilkoot Lake drainage during fall 1997 versus lengths of marked fish recaptured during spring 1998 (top)**, and versus lengths of fish examined for marks during spring 1998** (bottom)**.**

Table 3.–Results of chi-square tests to determine size categories for stratifying the mark-recapture experiment.

Length category	Length mm (FL)	Not marked	Marked	Total examined	Marked proportion
I	220–239	77	3	80	0.038
II	240–259	139	8	147	0.054
III	260–279	200	9	209	0.043
IV	280–309	364	9	373	0.024
V	≥310	884	6	890	0.007

Hypothesis A:
$H_O : P_I=P_{II}$
Result: $\chi^2 = 0.322$, df = 1, P = 0.571; accept H_O.

Hypothesis B:
$H_O : P_{I+II}=P_{III}$
Result: $\chi^2 = 0.072$, df = 1, P = 0.788; accept H_O.

Hypothesis C:
$H_O : P_{I+II+III}=P_{IV}$
Result: $\chi^2 = 2.75$, df = 1, P = 0.097; reject H_O.

Hypothesis D:
$H_O : P_{IV}=P_V$
Result: $\chi^2 = 6.77$, df = 1, P = 0.009; reject H_O.

CONCLUSION: Stratify experiment by three size classes:

$P_{I+II+III}$ = 220-279 mm,

P_{IV} = 280-309 mm, and

P_V = ≥310 mm.

Table 4.–Sampling statistics and estimated abundance of Dolly Varden in Chilkoot Lake by size category during winter 1997–1998.

Size	Fork length (mm)	Number marked (n_1)	2nd sampling event		Overwinter abundance	
			Examined (n_2)	Recaptured (m_2)	Estimate	SE
Medium	220–279	1,766	436	20	36,769	7,603
Large	280–309	488	373	9	18,288	5,384
X-large	≥310	424	890	6	54,095	18,893
Total	≥220	2,678	1,699	35	109,152	21,065

Table 5.–Estimated ages, sex, and size composition of Dolly Varden harvested in the Chilkoot sport fishery, June 28 to October 17, 1998.

	Otolith age	Fork length (mm)			Weight (g)		
		n	Mean	SE	n	Mean	SE
Males	3	2	223		2	110	20
	4	7	308	12	7	277	42
	5	35	342	4	34	367	17
	6	28	373	7	27	512	35
	7	16	426	6	15	728	41
	8	3	475	8	3	887	113
	9	2	483	18	2	850	250
Number aged		93					
Number sexed[a]		97	**% male** = 55.1		**SE** = 3.8		
Females	3	1	270		1	200	
	4	8	316	9	8	301	3
	5	31	331	5	30	336	5
	6	21	368	6	19	480	4
	7	6	404	7	6	570	2
	8	5	438	12	5	798	2
Number aged		72					
Number sexed[a]		79	**% female** = 44.9		**SE** = 3.8		
Combined[b]	3	3	238	17	3	140	32
	4	17	306	8	15	290	22
	5	68	337	3	64	353	13
	6	50	371	5	46	499	23
	7	22	420	5	21	683	34
	8	8	452	10	8	831	76
	9	2	483	18	2	850	250
Number aged		170					
Number sexed		176					
Number sampled		184					

[a] Includes fish that were not aged.

[b] Includes fish that were not sexed.

ranged from 0.880 to 1.880 and $\mu_{35\%}$ 0.093 to 0.067, for M ranging from 0.45 to 0.90 (Table 9, Figure 9). Plots for spawning abundance were similar to those for biomass and thus were omitted for brevity.

MIGRATION OF TAGGED FISH

Staff used individually numbered tags to mark 696 Dolly Varden in the Chilkoot drainage during this study. Eighty-five (85) of these were marked with visual implant (VI) tags and 122 with t-bar anchor tags during the fall of 1997. The remaining 489 Dolly Varden ≥350 mm FL were marked with t-bar anchor tags during the 1998 spring emigration.

Nine tagged fish were recovered in northern Southeast Alaska (Table 10). The majority of these (7) were recovered in the Chilkoot drainage: three were recovered during sampling of the spring emigration; two by a technician while sampling the angler harvest; and two were voluntarily turned in from the Chilkoot sport fishery. Only two (voluntary) recoveries were outside of the Chilkoot drainage: one from the Lynn Canal commercial drift gill net fishery; and the other from an angler fishing in the Taiya River near Skagway.

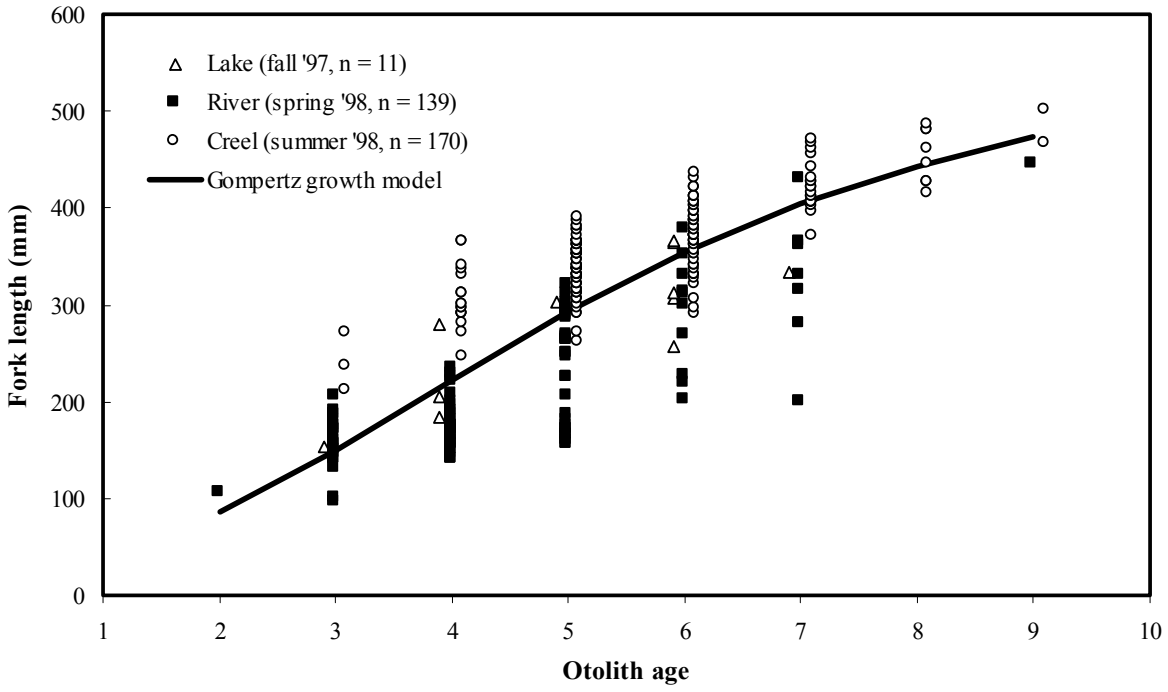


Figure 7.–Length at age for Dolly Varden sampled in the Chilkoot drainage during 1997 and 1998, showing predicted length from the Gompertz growth model.

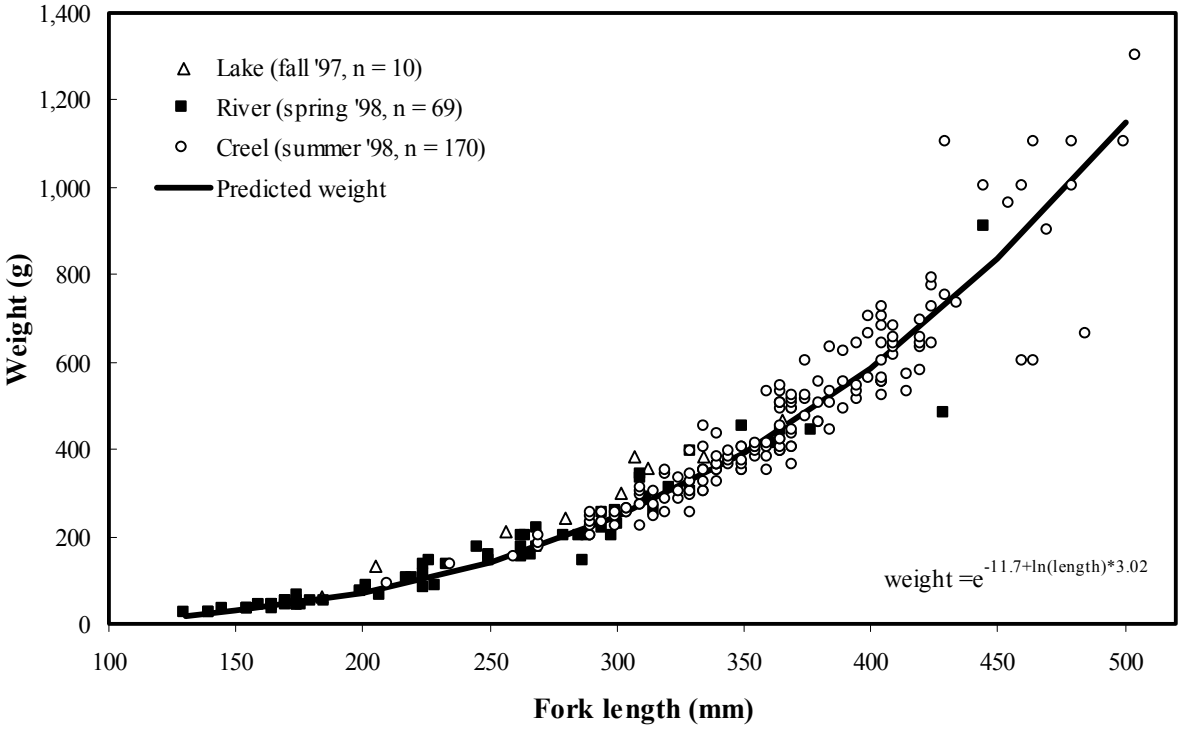


Figure 8.–Weight and length data from Dolly Varden sampled from the Chilkoot drainage, showing predicted weight from the weight-length model.

Table 6.–Number of anglers interviewed, total angler-hours of effort, and number of Dolly Varden caught, harvested, sampled and adipose finclips observed, by week during 1998.

Dates	Angler interviews	Angler-hours	Dolly Varden statistics			
			Catch	Harvest	Sampled	Adclips
06/28-07/04	72	74.3	21	10	5	0
07/05-07/11	29	46.5	47	6	6	0
07/12-07/18	58	94.3	71	13	12	0
07/19-07/25	89	149.8	53	24	21	1
07/26-08/01	138	262.7	49	13	12	1
08/02-08/08	144	242.7	85	8	6	0
08/09-08/15	157	285.8	117	25	21	0
08/16-08/22	149	267.2	82	17	15	1
08/23-08/29	96	193.4	33	13	9	0
08/30-09/05	54	46.0	13	8	8	0
09/06-09/12	94	137.5	25	8	8	0
09/13-09/19	49	104.3	123	31	24	3
09/20-09/26	94	98.1	110	18	18	0
09/27-10/03	109	243.3	66	9	8	0
10/04-10/10	198	502.3	27	11	8	0
10/11-10/17	98	251.8	24	3	3	0
Total	1,628	2,999.7	946	217	184	6

Table 7.–Estimated 1997–1998 overwinter abundance, and estimated harvest, exploitation rate, and number of Dolly Varden sampled in the Chilkoot drainage, by size category during 1998. Size categories were: small (<220 mm FL), medium (220–279 mm FL), large (280–309 mm FL), or x-large (≥310 mm FL).

	Overwinter abundance		Chilkoot Dolly Varden harvest				
	Number	SE	Sampled	Harvest	SE	Exploitation	SE
Small	ne[a]	ne	1	5	1	ne	ne
Medium	36,769	7,603	6	29	9	0.0008	0.0003
Large	18,288	5,384	22	108	32	0.0059	0.0025
X-large	54,095	18,893	155	760	223	0.0140	0.0064
All sizes	ne	ne	184	902[b]	265[b]	ne	ne
Med-Xlarge	109,152	21,065	183	897	226	0.0082	0.0026

[a] ne = No estimate available. [b] Howe et al. (1999).

Table 8.–Parameters used in the analysis of sustained yield for Chilkoot Dolly Varden and a comparison of the modeled and observed age composition of the harvest for 1998 (unfished abundance at age, where M = 0.75).

Age	Abundance N_a at F = 0.1	Mean length (mm) $\bar{l}_a$	Mean weight (g) $\bar{w}_a$	Maturity m_a	Selectivity s_a	Harvest age composition	
						Modeled[a]	Observed
3	1,000	150	30	0.00	0.00	0.00	0.02
4	472	223	100	0.04	0.07	0.11	0.10
5	222	293	228	0.44	0.52	0.38	0.40
6	99	354	405	0.89	0.92	0.29	0.29
7	43	405	605	0.99	0.99	0.14	0.13
8	18	444	800	1.00	1.00	0.06	0.05
9	8	473	972	1.00	1.00	0.02	0.01

[a] Assuming M = 0.75 and $\mu = 0.01$.

Table 9.–Results of per recruit analysis showing the change in biological reference points (BRPs) for instantaneous rates of natural mortality values ranging from 0.45 to 0.90.

Natural mortality (M)	Biological reference points[a]			
	Spawning biomass		Spawning abundance	
	$F_{35\%}$	$\mu_{35\%}$	$F_{50\%}$	$\mu_{50\%}$
0.45	0.880	0.093	0.900	0.094
0.60	1.100	0.082	1.200	0.085
0.75	1.420	0.074	1.640	0.078
0.90	1.880	0.067	2.260	0.073

[a] Values of instantaneous fishing mortality (F) and overall fishery exploitation (μ), that reduce the unfished Dolly Varden spawning biomass by 35%, or spawning abundance to 50% of unfished level.

DATA FILES

Data collected during this study (Appendix B5) have been archived in ADF&G offices in Haines, Douglas, and Anchorage.

DISCUSSION

Validity of the mark-recapture estimate is contingent upon meeting the study assumptions. Assumption (a) is hard to validate. Because the population likely included resident fish, not all fish emigrated or had a chance of being examined for marks at the lake outlet. However, by using several types of sampling gear distributed throughout the lake during the fall marking event, I anticipated that every fish within each size group present in the sampled area had an equal probability of being marked. Also, marked and unmarked fish within each size group probably mixed completely between sampling events. Thus, I believe assumption (a) was reasonable for a stratified experiment, and the combined estimate included both resident and anadromous overwintering fish ≥220 mm FL. Because some natural mortality occurred between events, the abundance estimate is germane to the first (marking) event.

I do not believe that significant emigration occurred between sampling events (assumption b). Armstrong (1965) did not find any fall/winter emigration from Lake Eva. During the winter of 1990 an angler caught a Dolly Varden in Mosquito Lake that had been tagged in Chilkat Lake the previous fall (Ericksen and Marshall 1991b). However, this recovery was the only one prior to the spring emigration from Chilkat Lake despite an intensive downstream fishery, so this recovery appeared to be very rare. Some Dolly Varden may overwinter in salt water (Bernard et al. 1995), but it is unlikely that these fish would have been sampled in this study.

Also, growth recruitment did not appear to be a problem. Overwinter (mid-October through mid-May) growth of tagged Dolly Varden in Chilkat Lake in 1990 averaged only 3 mm (Ericksen and Marshall 1991b). During the spring emigration, 3 Dolly Varden were recovered that had been tagged the previous fall (Table 10). Two fish did not grow at all, and one grew 39 mm (possible measurement error). Mean growth was not significantly different from 0 (12 mm, SE = 13 mm). Thus, I could not detect significant growth with the small number of samples.

In Lake Eva, Armstrong (1965) found that only 2.7% of the annual immigration occurred after October. Thus, I do not believe that a significant number of immigrants entered the system after the marking event. In contrast, because the marked fraction declined with fish size (Table 3), it was obvious that large fish either avoided our sampling gear, or were not equally available in the lake during the fall. If the large fish were not available (e.g., spawning in tributaries that were not sampled), then some recruitment/immigration did occur into the population. Assuming that within each size group all fish suffered similar overwinter mortality rates, the abundance estimate is unbiased.

I do not believe there was a failure of the other assumptions. I had no evidence that marking reduced the overwinter survival or subsequent catchability (assumption c), and incidental mortalities were removed from the marked population. Water temperatures were low during the marking event, decreasing stress (and mortality) on marked fish. Also, because different gear was

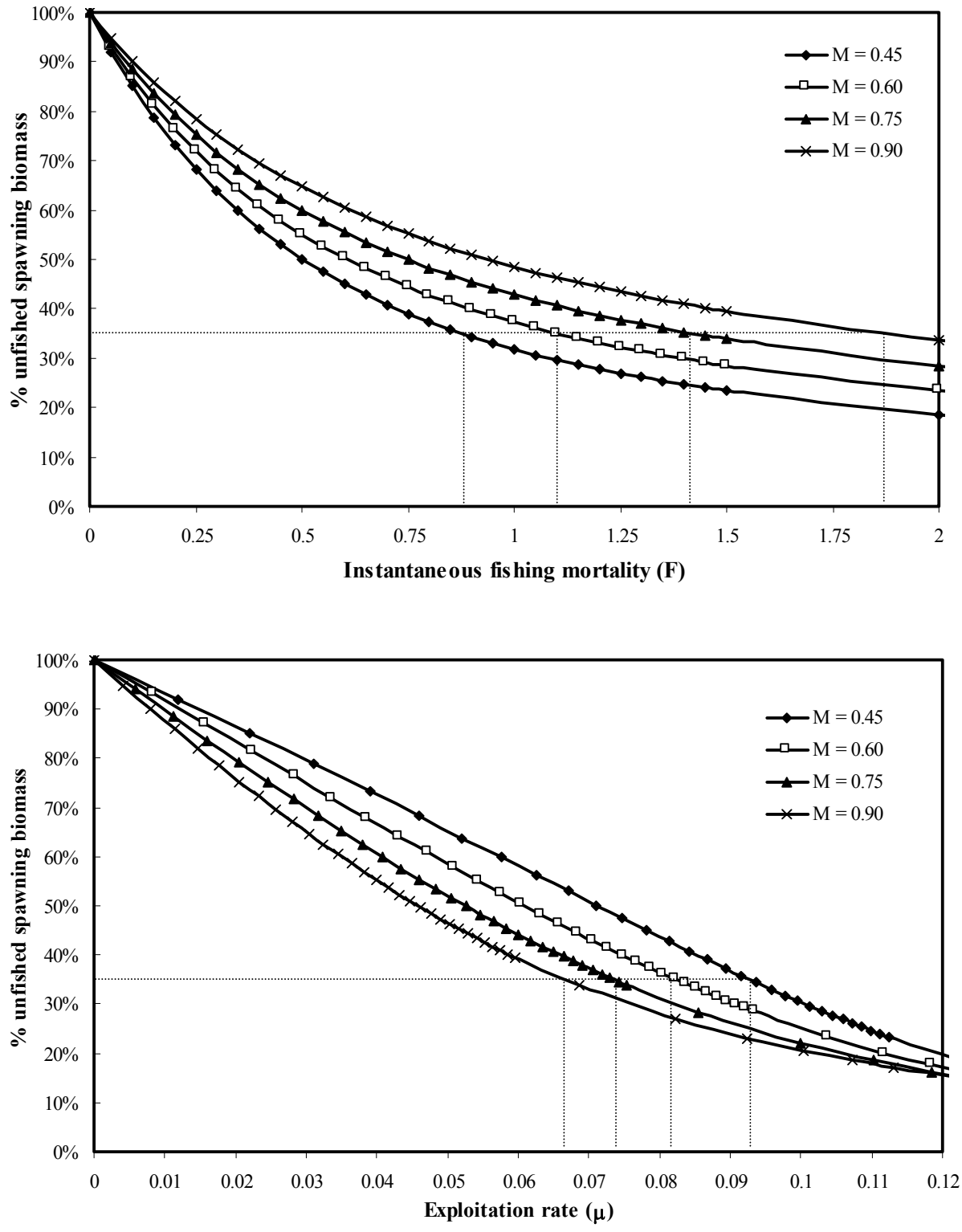


Figure 9.–Results of per recruit analysis for Chilkoot Dolly Varden showing the percent of unfished Chilkoot Dolly Varden spawning biomass as a function of instantaneous fishing mortality (top) **and exploitation rate** (bottom) **for 4 values of natural mortality.** Dashed lines represent the values that reduce the spawning biomass by 35%.

Table 10.–Recoveries through 1999 of Dolly Varden tagged in the Chilkoot drainage with visual implant (VI) or t-bar anchor (Floy®) tags during this study.

Tagging information					Recovery information					
Date	Location	Tag #	Tag type	Length (mm)	Date	Length (mm)	Source[a]	Location	Days out	Growth (mm)
09/16/97	Lake	A22	VI	280	05/22/98	319	ADFG	Chilkoot River	248	39
09/16/97	Lake	A28	VI	305	08/06/98	330	Creel	Chilkoot landing	324	25
09/18/97	Lake	3220	Floy	240	05/18/98	240	ADFG	Chilkoot River	242	0
09/18/97	Lake	3221	Floy	245	05/18/98	243	ADFG	Chilkoot River	242	-2
04/13/98	River	2259	Floy	356	07/08/98	460	Creel	Chilkoot landing	86	104
05/01/98	River	2478	Floy	398	July 1998		DGN	Lynn Canal		
05/02/98	River	2559	Floy	415	02/25/99		Sport	Taiya River	299	
05/19/98	River	2744	Floy	394	07/21/98		Sport	Chilkoot Lake	63	
05/19/98	River	2749	Floy	360	08/23/98		Sport	Chilkoot Lake	96	

[a] ADFG = recovered by ADF&G crew during the spring emigration; Creel = recovered by the creel technician while sampling angler harvests, DGN = voluntary recovery from the commercial drift gill net fishery; and Sport = voluntary recovery by a sport angler.

used during the marking and recovery events and there was a long hiatus (5 months) between events, trap avoidance (assumption c) was unlikely. Dolly Varden cannot regenerate their adipose fin in one winter, thus they cannot lose their mark (assumption d). Technicians could have failed to detect an adipose finclip if they were not careful. Thus, I stressed the importance of carefully inspecting each fish for marks (assumption e). Finally, all Dolly Varden sampled at the lake were marked with a lower caudal finclip and those at the lake outlet were marked with an upper caudal finclip. Thus, technicians were able to identify fish that were previously sampled and remove them from the experiment (assumption e).

Dolly Varden sampled in the angler harvest during 1998 were compared to those sampled in 1989 (Ericksen et al. 1990) and 1990 (Ericksen and Marshall 1991b). The most common estimated age of Dolly Varden sampled in 1998 (40% age 5) was younger than estimated in 1989 (31% age 6) and 1990 (36% age 7). It is possible this difference is due to different age determination methods rather than changes in the age structure of the harvest. Some differences were evident in the length distribution of Dolly Varden sampled in the three years (Table 11, Figure 10). The size composition of the 1998 harvest was significantly different from the 1989 ($\chi^2 = 4.75$, df = 2, P = 0.093), but not the 1990 harvest ($\chi^2 = 1.43$, df = 2, P = 0.489). The sex composition was roughly equal in all years sampled (1989 = 51% males, 1990 = 47% males, 1998 = 55% males).

The similarities between the harvest size compositions are surprising given regulation changes. In 1989 and 1990, anglers were allowed to keep 10 Dolly Varden per day compared to 2 in 1998. I expected anglers to be more selective toward harvesting larger fish when restricted to 2 fish.

Different people, equipment, and otolith preparation methods were used to estimate Dolly Varden ages in this study than in 1989 and 1990. Otoliths used in 1989 and 1990 were partially cleared by soaking in a glycerine solution about 48 hours and partially ground prior to viewing with an American Optical stereomicroscope. I believe that the equipment and methods used in this study were superior to those used then. Unfortunately, otoliths from past studies were stored in a glycerine solution and cleared to such

Table 11.–Number and percent of Dolly Varden sampled in the Chilkoot sport fishery by size category and year. Size categories were: small (<220 mm FL), medium (220–279 mm FL), large (280–309 mm FL), or x-large (≥310 mm FL).

	Size category				
	Small	Medium	Large	X-large	**Total**
1989 samples					
n	0	18	30	165	213
Percent		8.5	14.1	77.5	
SE		1.9	2.4	2.9	
1990 samples					
n	0	6	9	112	127
Percent		4.7	7.1	88.2	
SE		1.9	2.3	2.9	
1998 samples					
n	1	6	20	155	182
Percent	0.5	3.3	11.0	85.2	
SE	0.5	1.3	2.3	2.6	
Pooled samples					
n	1	30	59	432	522
Percent	0.2	5.7	11.3	82.8	
SE	0.2	1.0	1.4	1.7	

a degree that they could not be re-aged. Also, ages estimated from otoliths sampled from Dolly Varden in Alaska have not been validated. Aging error can bias per recruit analysis (Lai and Gunderson 1987, Ericksen 1997, Coggins and Quinn 1998). Thus, I recommend that the aging error associated with Dolly Varden otoliths be evaluated in the near future.

Paired age-length data used to model growth came from three different sources that were each size selective to some degree (Figure 7). Samples collected from the angler harvest (Table 5) appeared to be larger at age than those collected during the fall of 1997 (Appendix B1) and the spring of 1998 (Appendix B2). Both the fall marking and spring recovery events were size selective (see overwinter abundance results). In addition, Dolly Varden sampled during the spring should grow significantly through the summer and therefore were smaller at age than those sampled later in the year. Also, sport anglers tend to harvest the larger fish in the population. To help reduce the individual biases, I pooled sample sources for the growth modeling.

Dolly Varden tagged in this study were not recovered very far from Chilkoot Lake. Of the two recoveries outside of the Chilkoot drainage, the farthest was recovered in the Taiya River (32 km in salt water). Dolly Varden tagged in Chilkat Lake were recovered up to 202 km from the tagging site (Ericksen and Marshall 1991b). The probability of recovering a tagged fish was very low in this study relative to the study in Chilkat Lake. Thus, the two recoveries outside of the Chilkoot drainage are not sufficient to describe migration patterns of Chilkoot Dolly Varden. The angler who caught the tagged fish in the Taiya River also reported seeing several more tagged Dolly Varden in the river at the time. Because this Dolly Varden was caught in February, it is apparent that some Dolly Varden that overwintered in Chilkoot Lake during 1997–1998 overwintered in the Taiya River the following winter. This is in contrast to the paradigm that once Dolly Varden select a lacustrine watershed in which to overwinter, they continue to use that watershed as their winter habitat (Bernard et al. 1995).

The Dolly Varden harvest in the 1998 Chilkoot sport fishery was the lowest on record (Figure 11). For the first time in recent history, the Chilkoot sport fishery was closed to retention of sockeye salmon by emergency order on June 26, 1998. Because many anglers travel from other areas specifically to harvest Chilkoot sockeye salmon, sport fishing effort was noticeably lower during 1998. As a result, the exploitation of Dolly Varden in this fishery was lower than average.

My analysis indicates that the maximum sustainable exploitation rate for Chilkoot Dolly Varden is somewhere between 0.067 and 0.094 assuming M values of 0.90 to 0.45 (Table 9). In contrast, the estimated exploitation rate in 1998 was 0.008 (SE = 0.003, Table 7). Clearly, this exploitation rate was within acceptable limits. My results indicate that, at current population levels, the maximum sustainable harvest is

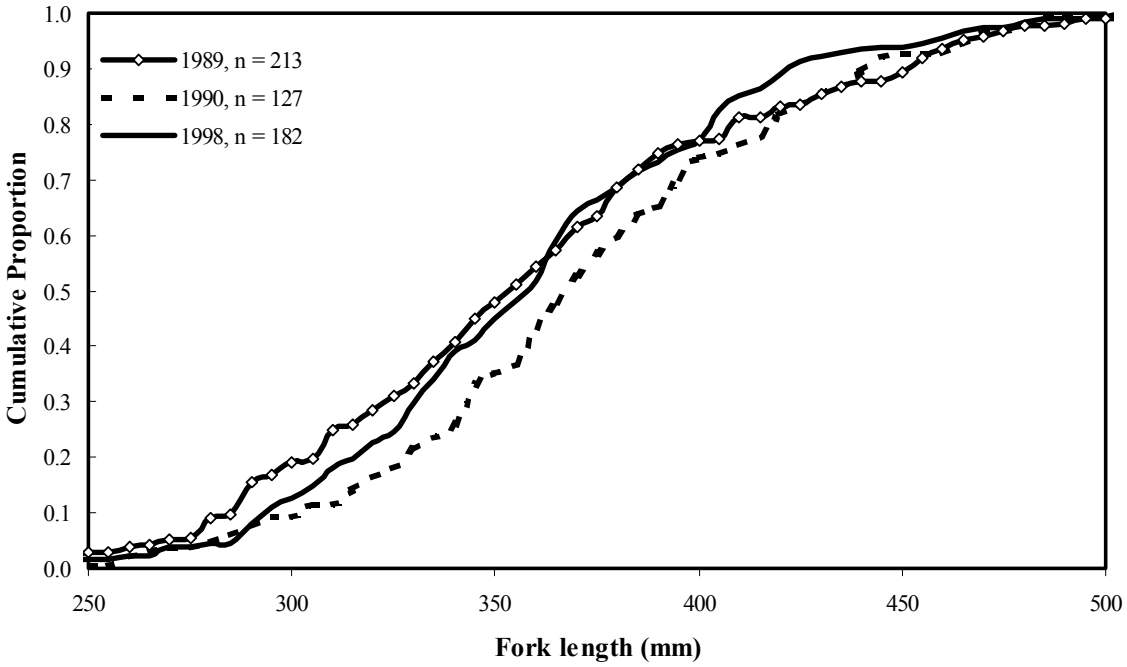


Figure 10.–Cumulative distribution function (CDF) of lengths (FL) of Dolly Varden sampled in the Chilkoot sport fishery in 1989, 1990, and 1998 (1989 data modified from Ericksen et al. 1990; 1990 data modified from Ericksen and Marshall 1991b).

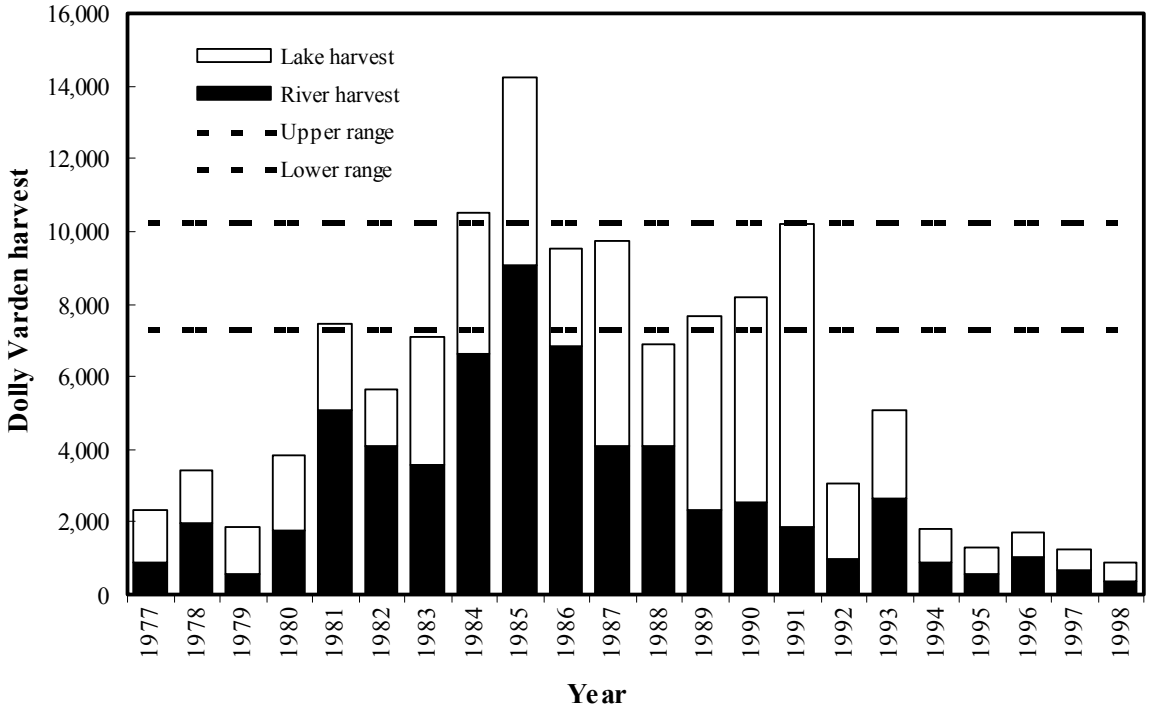


Figure 11.–Sport harvest of Dolly Varden in Chilkoot Lake and River, 1977–1998 (data from SWHS). Dashed lines represent the upper (M = 0.45) and lower (M = 0.90) maximum sustainable harvest ranges determined from the per recruit analysis. Because of the uncertainty in estimating M, I recommend using the lower range for managing this population.

somewhere between 7,313 and 10,260 (Figure 11).

Natural mortality is a difficult parameter to measure, and estimates for Dolly Varden are highly variable. Larson (1997) estimated instantaneous rates of natural mortality for anadromous Dolly Varden aged 5 to 8 in the Anchor River ranged from 0.186 to 3.425 over seven years. Because of the uncertainty about the rate of natural mortality for this population, and because aging error was not evaluated in this study, I recommend using the lowest BRP value ($\mu_{35\%}$ = 0.067) to monitor this fishery. The Dolly Varden harvest in the Chilkoot sport fishery has been at or above the lower range eight times since 1977 suggesting that the population may have been overfished in the past (Figure 11). However, it has not approached this level since 1991. Thus, I believe that additional measures are not needed to restrict the harvest of Dolly Varden in this fishery at the present time.

I recommend implementing a minimum size restriction if future harvests approach 7,000 fish. Based on the size composition of the harvest, a minimum (total) length limit of 12 in. would reduce the harvest by about 9% (13 in. = 21%, 14 in. = 40%).

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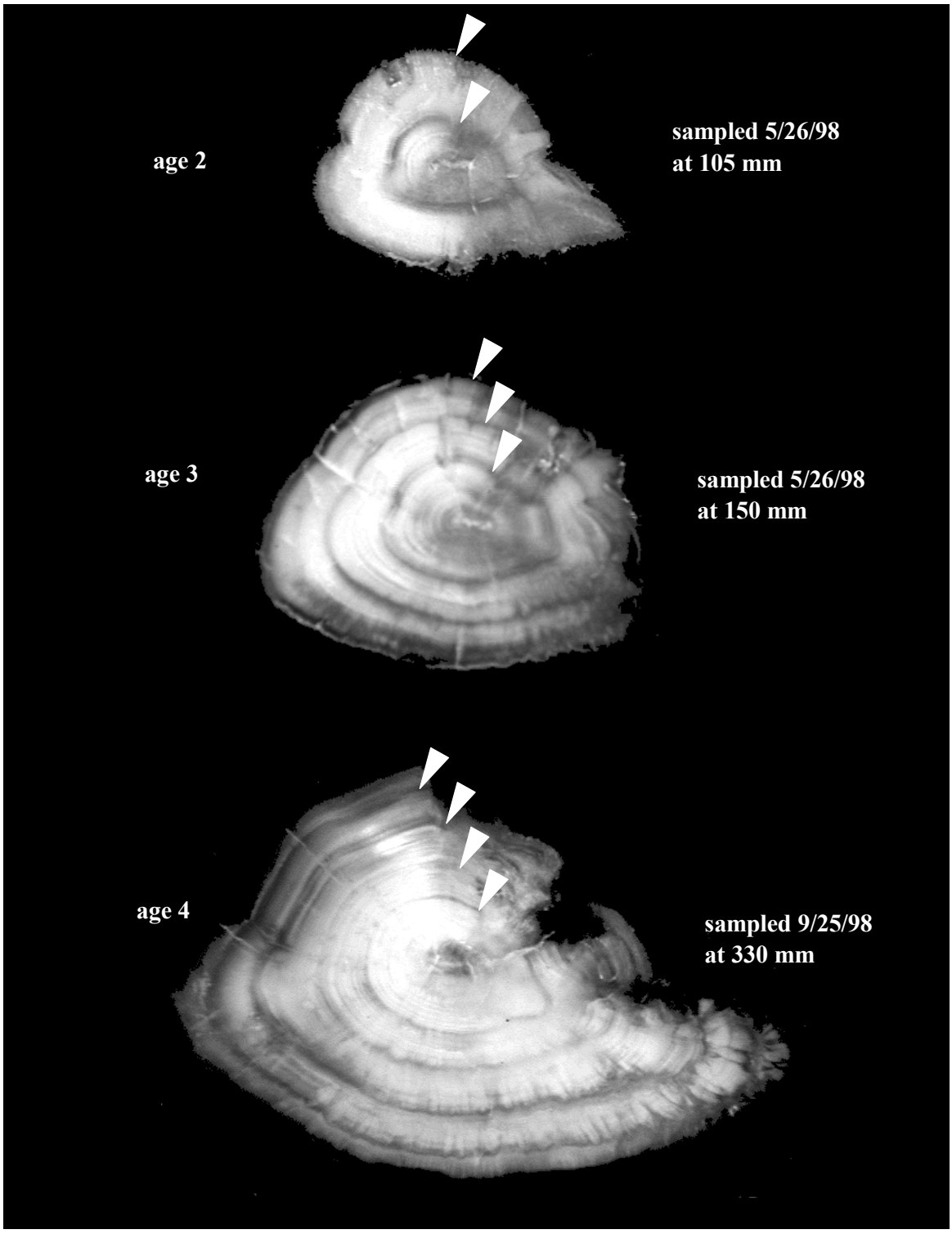
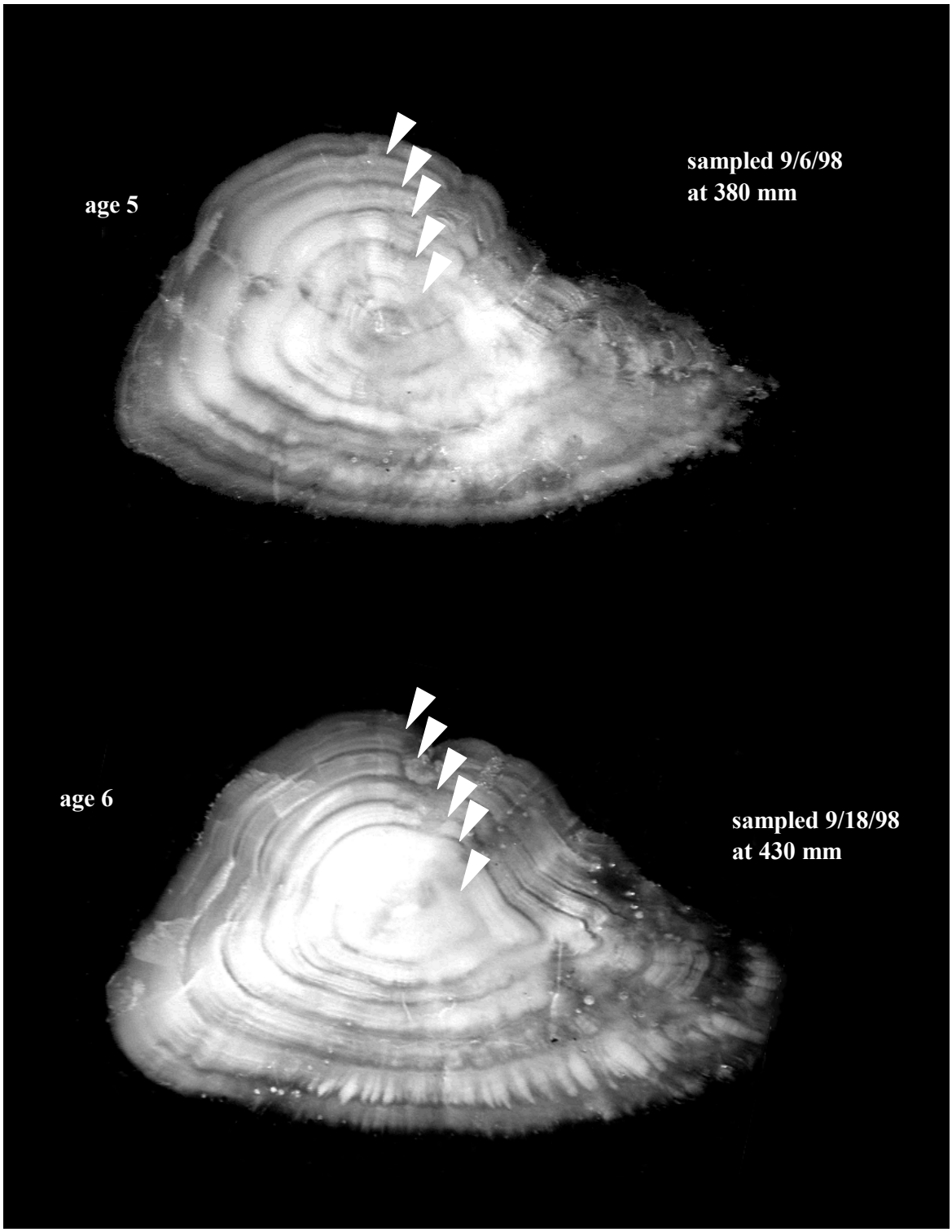
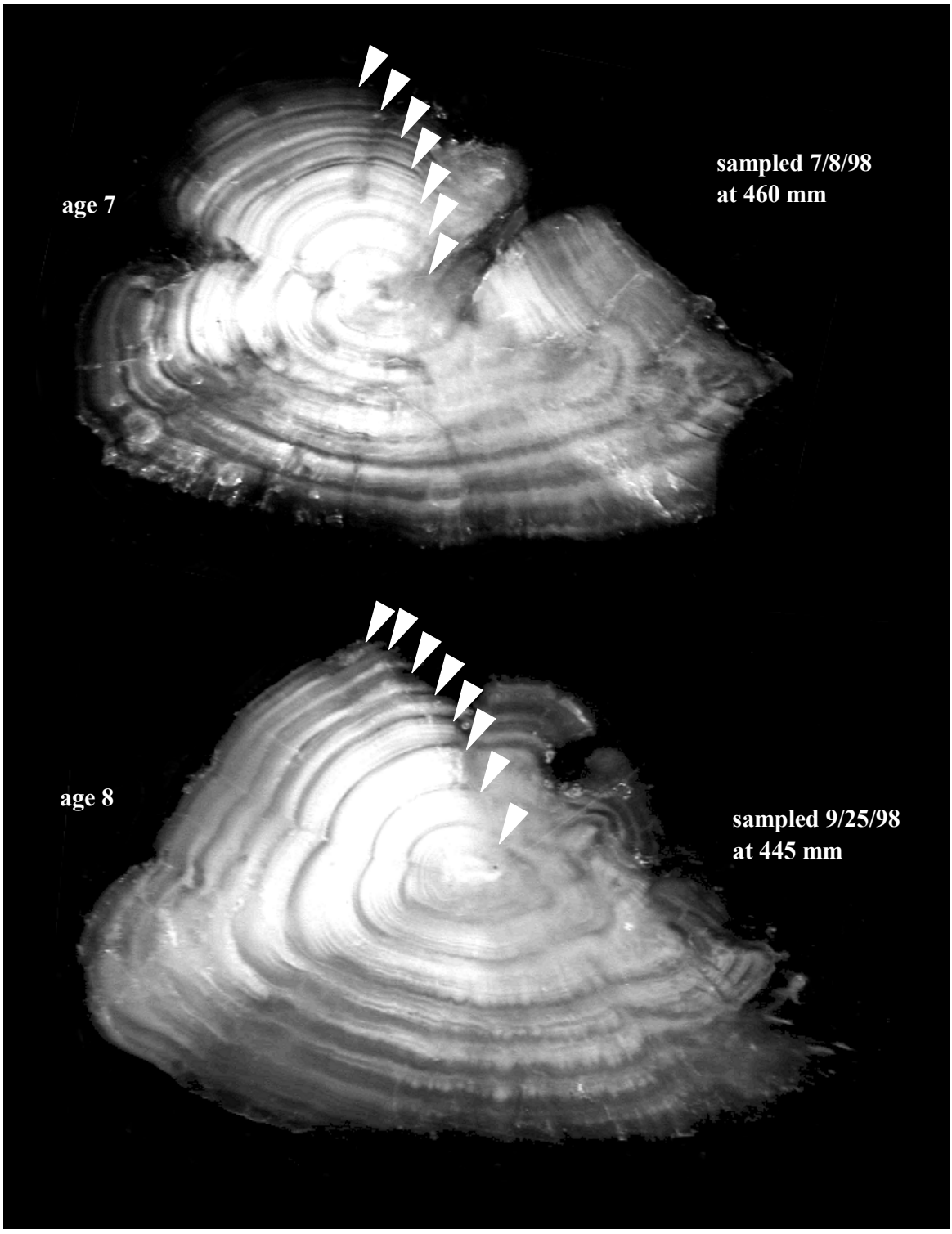
APPENDIX A



Appendix A1.–Otoliths collected in the Chilkoot drainage from Dolly Varden of estimated ages 2–4.



Appendix A2.–Otoliths collected in the Chilkoot drainage from Dolly Varden of estimated ages 5 and 6.



Appendix A3.–Otoliths collected in the Chilkoot drainage from Dolly Varden of estimated ages 7 and 8.

APPENDIX B

Appendix B1.–Age, sex, and size composition of Dolly Varden mortalities sampled in Chilkoot Lake during the fall of 1997.

	Otolith age	Length			Weight		
		n	Mean	SD	n	Mean	SD
Male	4	3	223	24	3	144	42
	6	4	310	19	4	354	46
Number aged		7					
Number sexed		7	% males = 70.0%		SD = 14.5%		
Female	5	1	302		1	300	
	6	1	365		1	465	
	7	1	334		1	385	
Number aged		3					
Number sexed		3	% females = 30.0%		SD = 14.5%		
Combined[a]	3	1	153				
	4	3	223	24	3	144	42
	5	1	302		1	300	
	6	5	321	18	5	376	42
	7	1	334		1	385	
Number aged		11					
Number sexed		10					
Number sampled		11					

[a] Includes one fish that was not sexed.

Appendix B2.–Age, sex, and size composition of Dolly Varden mortalities sampled in the Chilkoot River during spring 1998.

	Otolith	Length			Weight		
	age	n	Mean	SD	n	Mean	SD
Male	2	1	105	0	1	10	0
	3	20	158	5	20	36	4
	4	34	171	4	34	45	4
	5	16	220	12	16	113	17
	6	3	289	26	3	287	62
	7	3	280	38	3	227	81
Number aged		77					
Number sexed		77	% males = 55.8%		SD = 4.2%		
Female	3	13	157	6	13	38	4
	4	19	174	4	19	49	5
	5	17	241	15	17	153	25
	6	7	290	23	7	247	53
	7	4	360	22	4	369	47
	9	1	445		1	905	0
Number aged		61					
Number sexed		61	% females = 44.2%		SD = 4.2%		
Combined[a]	2	1	105		1	10	
	3	33	157	4	33	37	3
	4	53	172	3	53	47	3
	5	34	231	9	34	132	15
	6	10	289	18	10	259	42
	7	7	326	25	7	308	51
	9	1	445		1	905	
Number aged		139					
Number sexed		138					
Number sampled		139					

[a] Includes one fish that was not sexed.

Appendix B3.–Parameter estimates, summary statistics, and hypothesis tests from Schnute growth models fitted to age and length data for 320 Dolly Varden sampled from the Chilkoot drainage by assuming and additive error structure. Parameters y_1 and y_2 correspond to estimated lengths at age 2 (τ_1) and 9 (τ_2).

	Case 1	Case 2	Case 3	Case 4	Case 5
$\hat{y}_1 \pm 1$ SE	101±16.5	85.4±11.3	62.0±30.9	161±5.24	65.7±17.9
$\hat{y}_2 \pm 1$ SE	452±21.7	473±17.0	505±15.2	581±17.2	490±17.5
$\hat{\kappa} \pm 1$ SE	0.726±0.401	0.362±0.055	set to 0	set to 0	0.122±0.049
$\hat{\gamma} \pm 1$ SE	-1.52±1.72	set to 0	1.41±0.204	set to 0	set to 1
Correlations					
$(\hat{y}_1, \hat{y}_2)$	-0.401	0.550	0.558	-0.722	0.535
$(\hat{y}_1, \hat{\kappa})$	0.760	-0.895			-0.847
$(\hat{y}_1, \hat{\gamma})$	-0.855		-0.899		
$(\hat{y}_2, \hat{\kappa})$	-0.782	-0.845			-0.867
$(\hat{y}_2, \hat{\gamma})$	0.702		-0.826		
$(\hat{\kappa}, \hat{\gamma})$	-0.986				
Summary statistics and hypothesis tests					
Residual *df*	316	317	317	318	317
RSS	1,020,553	1,025,912	1,044,829	1,198,837	1,037,014
RMS ($\hat{\sigma}^2$)	3,230	3,236	3,296	3,770	3,271
F vs Case 1		1.66	7.52	17.6	5.10
		(*P*=0.199)	(*P*=0.007)	(*P*<0.001)	(*P*<0.001)
F vs Case 2				53.4	
				(*P*<0.001)	
F vs Case 3				46.7	
				(*P*<0.001)	
F vs Case 5				42.9	
				(*P*<0.001)	

Appendix B4.–Number of interviews, angler-hours of effort, Dolly Varden caught, harvested, sampled, and sampled with adipose finclips, and catch and harvest of salmon species, by area and week in the Chilkoot drainage during 1998.

		Angler-	Dolly Varden				Sockeye	Pink		Coho	
Dates	Interviews	hours	Catch	Harvest	Sampled	Adclips	catch	Catch	Harvest	Catch	Harvest
Chilkoot Lake											
06/28-07/04	12	12.8	4	2	1	0	0	0	0	0	0
07/05-07/11	5	9.0	28	1	1	0	0	0	0	0	0
07/12-07/18	3	44.0	30	0	0	0	2	0	0	0	0
07/19-07/25	1	12.0	15	5	5	1	2	0	0	0	0
07/26-08/01	8	67.0	37	8	8	1	0	0	0	0	0
08/02-08/08	17	86.0	66	3	3	0	3	5	0	0	0
08/09-08/15	9	43.5	18	0	0	0	20	0	0	0	0
08/16-08/22	4	57.5	21	0	0	0	5	5	1	0	0
08/23-08/29	2	22.5	12	2	2	0	0	8	6	0	0
08/30-09/05	1	0.5	1	1	1	0	0	0	0	0	0
09/06-09/12	2	21.0	6	0	0	0	4	6	0	0	0
09/13-09/19	3	63.0	39	5	5	1	5	10	0	0	0
09/20-09/26	0	0.0	0	0	0	0	0	0	0	0	0
09/27-10/03	23	56.8	21	0	0	0	0	0	0	18	18
10/04-10/10	56	202.8	6	1	1	0	0	0	0	53	53
10/11-10/17	16	79.5	16	1	1	0	0	0	0	14	14
Area total	162	777.8	320	29	28	3	41	34	7	85	85
Chilkoot Lake landing											
06/28-07/04	30	30.7	9	4	2	0	0	0	0	0	0
07/05-07/11	12	17.5	13	2	2	0	0	0	0	0	0
07/12-07/18	33	30.8	35	10	10	0	0	0	0	0	0
07/19-07/25	36	41.0	22	11	9	0	0	3	2	0	0
07/26-08/01	53	79.9	3	1	0	0	0	8	6	0	0
08/02-08/08	32	29.8	5	4	2	0	2	7	5	0	0
08/09-08/15	52	52.8	59	19	17	0	0	17	4	0	0
08/16-08/22	16	33.9	14	11	11	1	0	7	2	0	0
08/23-08/29	12	19.8	5	3	3	0	0	40	4	0	0
08/30-09/05	30	26.5	10	5	5	0	1	46	1	1	1
09/06-09/12	42	40.3	19	8	8	0	0	77	0	0	0
09/13-09/19	31	27.8	38	16	9	2	0	3	0	0	0
09/20-09/26	51	45.1	57	11	11	0	6	7	0	7	6
09/27-10/03	23	44.5	9	3	2	0	0	0	0	6	5
10/04-10/10	40	65.0	9	6	3	0	0	0	0	9	9
10/11-10/17	19	21.5	1	0	0	0	0	0	0	1	0
Area total	512	606.6	308	114	94	3	9	215	24	24	21

-continued-

Appendix B4.–Page 2 of 2.

Dates	Interviews	Angler-hours	Dolly Varden				Sockeye	Pink		Coho	
			Catch	Harvest	Sampled	Adclips	catch	Catch	Harvest	Catch	Harvest
Chilkoot River above F&G weir											
06/28-07/04	3	2.6	0	0	0	0	0	0	0	0	0
07/05-07/11	1	3.0	2	0	0	0	0	0	0	0	0
07/12-07/18	0	0.0	0	0	0	0	0	0	0	0	0
07/19-07/25	0	0.0	0	0	0	0	0	0	0	0	0
07/26-08/01	2	0.8	0	0	0	0	0	0	0	0	0
08/02-08/08	4	1.5	0	0	0	0	0	1	1	0	0
08/09-08/15	3	18.0	15	3	3	0	1	0	0	0	0
08/16-08/22	7	1.7	1	1	1	0	0	3	0	0	0
08/23-08/29	4	8.0	0	0	0	0	0	15	0	0	0
08/30-09/05	8	6.5	2	2	2	0	0	20	2	1	1
09/06-09/12	4	1.8	0	0	0	0	0	3	0	0	0
09/13-09/19	13	12.5	46	10	10	0	0	7	0	1	1
09/20-09/26	43	53.0	53	7	7	0	0	3	0	12	9
09/27-10/03	60	136.1	30	5	5	0	0	0	0	46	41
10/04-10/10	98	230.6	10	4	4	0	0	0	0	50	48
10/11-10/17	50	111.8	6	2	2	0	0	0	0	10	10
Area total	300	587.6	165	34	34	0	1	52	3	120	110
Chilkoot River below F&G weir											
06/28-07/04	27	28.2	4	0	2	0	1	0	0	0	0
07/05-07/11	11	17.0	4	3	3	0	4	1	0	0	0
07/12-07/18	22	19.5	6	3	2	0	8	5	2	0	0
07/19-07/25	52	96.8	16	8	7	0	1	33	14	0	0
07/26-08/01	75	115.1	9	4	4	0	0	42	25	0	0
08/02-08/08	91	125.4	14	1	1	0	1	84	37	0	0
08/09-08/15	93	171.6	25	3	1	0	0	230	106	0	0
08/16-08/22	122	174.2	46	5	3	0	7	585	102	0	0
08/23-08/29	78	143.2	16	8	4	0	1	598	77	0	0
08/30-09/05	15	12.5	0	0	0	0	0	58	2	0	0
09/06-09/12	46	74.5	0	0	0	0	0	405	10	1	1
09/13-09/19	2	1.0	0	0	0	0	0	2	0	0	0
09/20-09/26	0	0.0	0	0	0	0	0	0	0	0	0
09/27-10/03	3	6.0	6	1	1	0	0	0	0	0	0
10/04-10/10	4	4.0	2	0	0	0	0	0	0	1	1
10/11-10/17	13	39.0	1	0	0	0	0	0	0	4	4
Area total	654	1,027.8	149	36	28	0	23	2,043	375	6	6
Grand total	1,628	2,999.7	942	213	184	6	74	2,344	409	235	222

Appendix B5.–Computer files used in the analysis of data for this report.

FILE NAME	DESCRIPTION
DV-CAP.XLS	Excel workbook containing all data collected during the 1997 fall marking, and 1998 spring recovery events.
DVPOPEST.XLS	Excel workbook used to estimate 1997-1998 overwinter abundance of Dolly Varden in Chilkoot Lake.
DVAWL.XLS	Excel workbook containing all Dolly Varden age-weight-length data collected during this study.
98DVINTS.XLS	Excel workbook containing angler interview information collected from the Chilkoot sport fishery during 1998.
DVTAGREC.XLS	Excel workbook containing recovery information from Dolly Varden tag returns.
KOOTEXP.XLS	Excel workbook used to estimate the 1998 sport exploitation of Chilkoot Dolly Varden.
DVGROWTH.XLS	Excel workbook containing Dolly Varden growth information.
DVPERREC.XLS	Excel workbook used in the per recruit analysis of Chilkoot Dolly Varden.
CTKOOT98.XLS	Excel workbook with cutthroat trout length information in the Chilkoot drainage.